

sierra research

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**Potential Emissions  
and Air Quality Effects  
of Alternative Fuels -  
Final Report**

March 28, 1989

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FINAL REPORT**

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### **Preface**

This report supercedes a November 30, 1988 report entitled "Potential Emissions and Air Quality Effects of Alternative Fuels". In addition to minor editorial changes, the November 30 report has been supplemented with information regarding the use of alternative fuels in heavy-duty engines and vehicles. An additional reference has also been incorporated regarding the information presented in the earlier report on the presence of non-methane hydrocarbons in the exhaust of engines using pure methanol (M100) fuel.

The "CMU Study" referenced in this report, refers to work published by Carnegie-Mellon University in August of 1988. Since then, a variety of changes to CMU's air quality modeling of methanol vehicle use have apparently been made. In considering this report in the context of any CMU work products, it should be noted that the only detailed information available to the authors was that published by CMU as of August 1988.



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## 1. SUMMARY

An analysis of available information on the emission characteristics and development status of alternatively-fueled vehicles indicates that:

- ⊙ Methanol offers no clear advantage over gasoline in reducing vehicle emission levels. Projections of significant air quality benefits for methanol have been based on overly optimistic assumptions regarding the ability to control reactive organic emissions and oxides of nitrogen (NO<sub>x</sub>) emissions from methanol combustion. Gasoline vehicles have already been certified at the emission levels projected for the use of "advanced technology" under a recent ARB-sponsored study by Carnegie Mellon University (CMU). In contrast, no methanol vehicle has ever demonstrated the level of emissions control assumed in the CMU study. Continued refinement of control technology should allow gasoline to retain its current advantage.
- ⊙ The emission characteristics of natural gas compare favorably to gasoline, but the relatively low energy density and refueling time requirements of natural gas are a disadvantage in many light-duty vehicle applications. Natural gas appears to be a more promising alternative for transit buses and other vehicle fleets that use centralized fueling facilities (e.g., garbage trucks, certain delivery trucks, etc.).
- ⊙ Liquefied petroleum gas (LPG) provides some of the air quality advantages of natural gas with significantly higher energy density. However, the potential emission control benefits of LPG over gasoline are less than with natural gas.
- ⊙ Methanol-fueled engines have lower particulate emissions than Diesel-fueled engines without traps, and some methanol-fueled engines also have lower NO<sub>x</sub>. However, catalytic control appears necessary to prevent increased emissions of formaldehyde compared to Diesel engines. Gasoline and compressed natural gas have at least as much potential to minimize emissions from heavy-duty vehicles. In addition, further development of particulate trap technology may allow Diesel-fueled vehicles to achieve particulate emissions comparable to methanol-fueled vehicles.

It has long been recognized that the organic compound emissions in the exhaust of methanol-fueled vehicles are less reactive than the organic emissions in the exhaust of gasoline-fueled vehicles. As a result, a number of air quality modeling studies have concluded that ozone

levels could be reduced by converting the motor vehicle fleet to methanol fuel. However, these studies have typically been based on the erroneous assumption that the oxides of nitrogen (NOx) emissions from methanol-fueled vehicles would be the same as from gasoline-fueled vehicles and that there would be no hydrocarbon emissions. Under this assumption, the lower reactivity of methanol vehicle exhaust results in reduced ozone generation, if one also assumes that formaldehyde emissions can be controlled adequately. In spite of these commonly used assumptions, gasoline-fueled vehicles are capable of achieving essentially equivalent reactive organic emission levels and substantially lower oxides of nitrogen emissions.

Research and development efforts to date indicate that methanol-fueled vehicles have not achieved organic and NOx emissions as low as gasoline-fueled vehicles when equipped with comparable levels of emission control technology. Sierra could not identify one single test of a methanol prototype that achieved the emission levels assumed to be possible under the recent CMU modeling study<sup>1\*</sup> of the air quality implications of methanol fuel utilization. In contrast, the test results from the late-model gasoline cars indicate that there are dozens of gasoline-fueled vehicles that are already certified at the lowest emission levels assumed for gasoline-fueled vehicles in the CMU study.

At the current state of emissions control technology development, gasoline-fueled vehicles have achieved more than 50% lower NOx emissions and equivalent or lower hydrocarbon emissions (computed as recommended by EPA), compared to methanol-fueled vehicles. This is illustrated in Figure 1, which shows the 50,000 mile certification test results for gasoline vehicles compared to methanol vehicles after several thousand miles of catalyst stabilization.

The top portion of Figure 1 illustrates the significant difference in demonstrated NOx emission control between methanol and gasoline-fueled vehicles. The best low mileage test results on the methanol prototypes that have been tested by ARB<sup>2</sup> have NOx emissions significantly higher than the best of the currently certified gasoline vehicles.<sup>3</sup> All popular manufacturers have demonstrated the capability to achieve NOx emissions below 0.3 g/mi. In contrast, none of the methanol prototypes tested by ARB have been below 0.3 g/mi, and most are above the 0.4 g/mi standard.

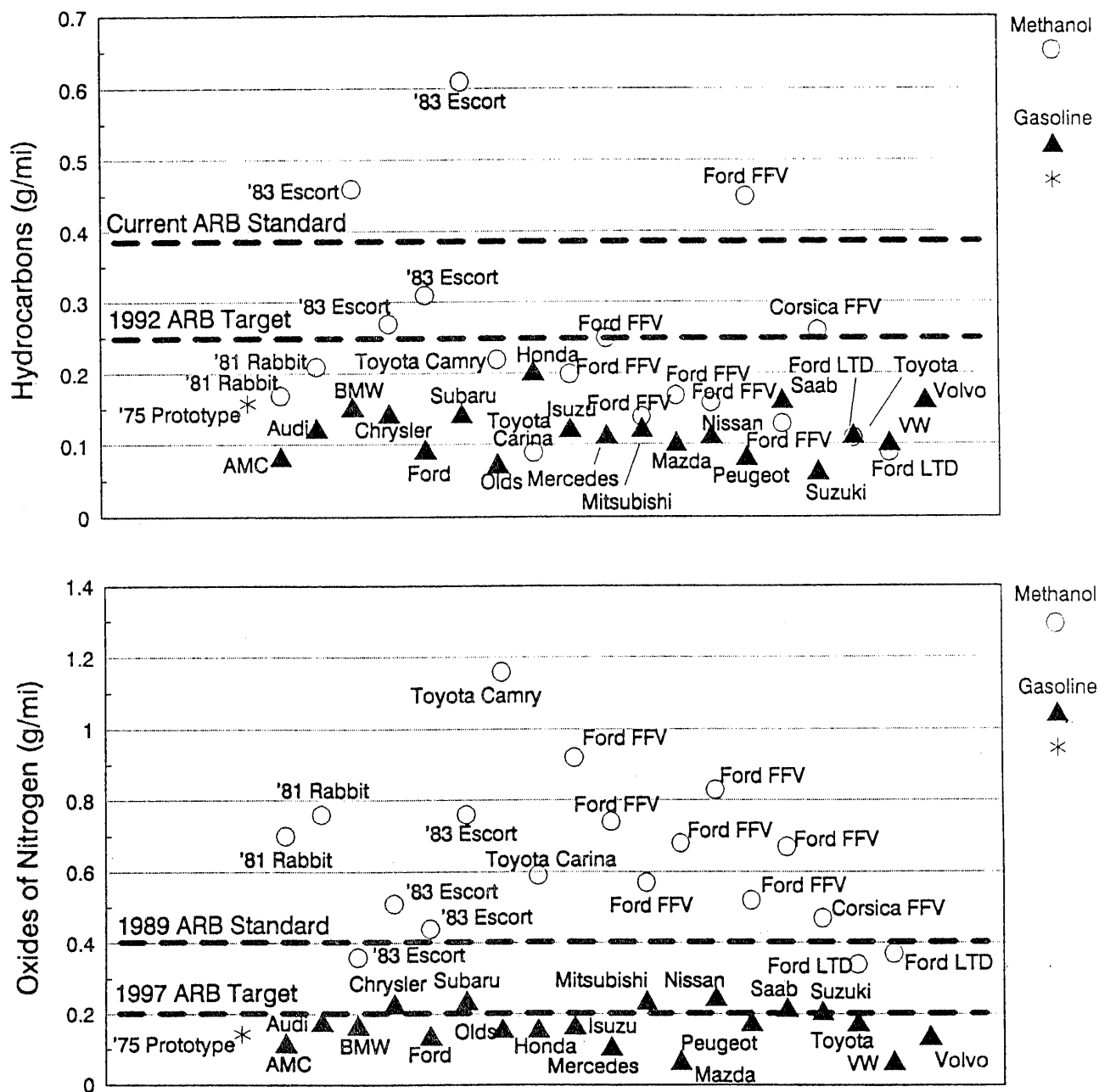
The fact that the methanol vehicles currently under test are "prototypes" should not be considered a disadvantage. Hand-built, carefully maintained prototype vehicles generally perform better than mass-produced vehicles. Figure 1 also shows data for a prototype gasoline vehicle under development by Ford during 1975. At approximately the same mileage as the methanol vehicles shown in the figure, Ford was achieving 0.17 g/mi NOx.<sup>4</sup> After 13 years of gasoline

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\* Superscripts denote references listed in Section 8.

Figure 1

## A Comparison of Gasoline and Methanol Vehicle Emissions of Oxides of Nitrogen and Hydrocarbons



Notes : Methanol vehicle emissions data are best ARB test results after catalyst stabilization (generally 4,000 miles). Gasoline vehicle emissions are 50,000 mile certification values.

Methanol vehicle emissions are based on Organic Material Hydrocarbon Equivalent "OMHCE" technique recommended by EPA. Gasoline vehicle emissions are NMHC.

emissions control system development, production vehicles are finally achieving the levels demonstrated with low-mileage prototype vehicles.

For methanol vehicles, the "hydrocarbon" emissions plotted in the bottom portion of Figure 1 are based on the EPA method, which includes only about half of the weight of the methanol and formaldehyde emitted by methanol-fueled vehicles (by subtracting the oxygen content of the organic emissions). As the figure shows, the low mileage "hydrocarbon" emissions of the methanol prototypes tested by the California Air Resources Board are generally slightly higher than the non-methane hydrocarbon (NMHC) emissions of the best gasoline models that have already been certified at 50,000 miles. Figure 1 also indicates that HC levels of 0.16 g/mi were being achieved with prototype gasoline vehicles 13 years ago.<sup>4</sup>

It should be noted that a significant fraction of the total organic emissions computed by the EPA method is unburned methanol, with relatively low photochemical reactivity. Because of this lower reactivity, methanol vehicles may be able to have higher total organic emissions and still have a reduced contribution to ozone formation. However, available test results indicate that combined total of the more highly reactive non-methane hydrocarbon and formaldehyde emissions from methanol vehicles are about as large as the non-methane hydrocarbons from the best of the current technology gasoline vehicles.

Ford has recently reported that non-oxygenated organic compounds (hydrocarbons) from both M85 (85% methanol/15% gasoline) and M100 (100% methanol) fuels are in the range of 0.25 g/mi.<sup>5</sup> This is in the same range as the hydrocarbon emissions from conventional gasoline vehicles. The fact that hydrocarbon emissions are emitted during the combustion of M100 has also been recently confirmed in research conducted by General Motors Corporation.<sup>22</sup>

Hydrocarbon emissions from vehicles using mixtures of methanol and gasoline (e.g., "M85") have been a recognized source of concern. However, it has generally been assumed that hydrocarbons would be essentially eliminated when pure methanol is used. Two factors have contributed to the creation of the misimpression that hydrocarbon emissions are of no concern with M100. First, most testing of methanol-fueled vehicles has been done using instrumentation that is incapable of accurately measuring hydrocarbon emissions. For example, all test results thus far published by EPA have been based on a procedure under which hydrocarbon emissions are estimated and not directly measured. Second, many of the published data regarding emissions from methanol-fueled vehicles reflect tests of vehicles with very low-mileage ("green") catalysts. Until about 4,000 miles have been accumulated, the performance of the catalyst-equipped vehicles does not reflect the level of control that can be expected in customer service.

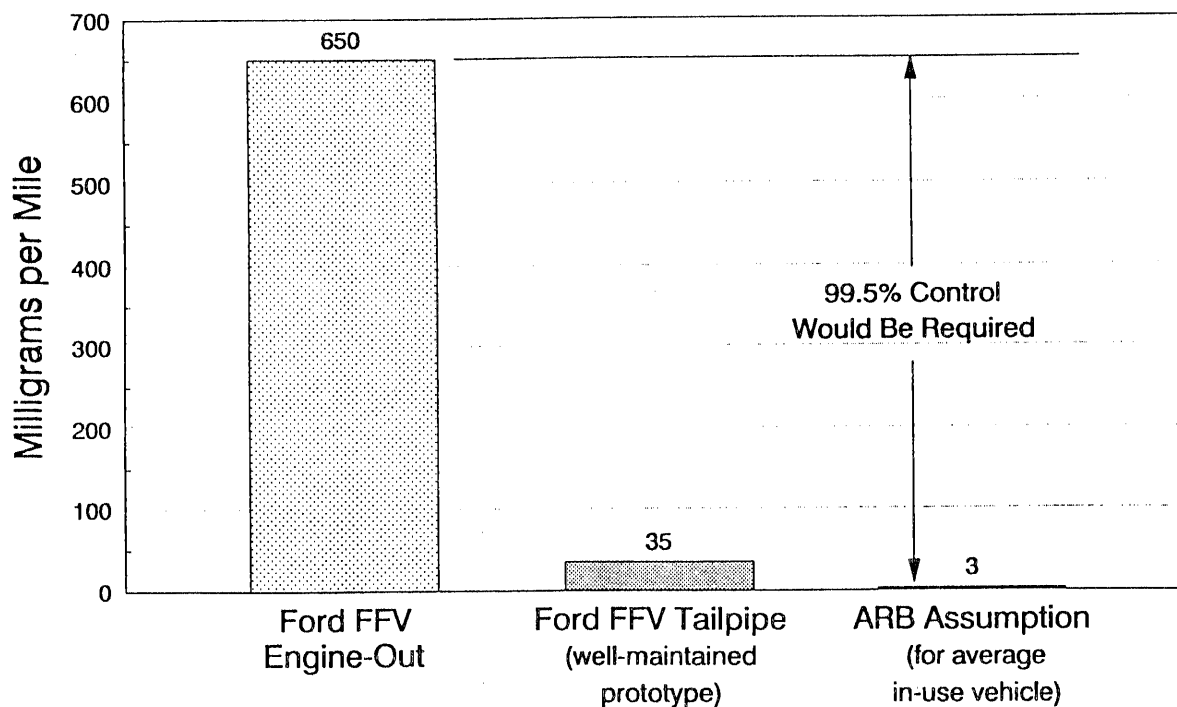
In addition to the fact that emissions of hydrocarbons continue to occur on M100 fuel, methanol vehicles emit substantially more

formaldehyde than do gasoline vehicles. Ford has reported pre-catalyst formaldehyde emission levels of 0.65 grams per mile (g/mi) on M100 fuel. This is nearly half of the pre-catalyst non-methane hydrocarbon emissions emitted by late-model gasoline engines.<sup>6, 7</sup> As illustrated in Figure 2, at this level of formaldehyde emissions, 99.5% catalyst efficiency would be required to achieve the formaldehyde emission levels that were assumed for M100 vehicles in the recent Carnegie Mellon University study. The unrealistic 3 mg/mi level of formaldehyde emissions for M100 vehicles assumed in the CMU study is lower than would be expected from catalyst-equipped gasoline vehicles that emit up to ten times less "pre-catalyst" formaldehyde. According to a recent Ford technical paper<sup>5</sup> discussing methanol-fueled vehicles:

"It does not appear possible that formaldehyde levels can be controlled to the level of gasoline vehicles. It is simply expecting too much to believe that a catalyst can maintain such high levels of efficiency for 50,000 miles."

As with hydrocarbon emissions, formaldehyde emissions reported for methanol are often based on low-mileage test results that do not represent the expected performance of vehicles with stabilized catalytic converter efficiency.

Figure 2  
**Formaldehyde Emissions  
From M100**



Using the most accurate and representative test data, it is apparent that methanol is not an inherently "clean" fuel. As with gasoline-powered vehicles, the control of emissions from methanol-fueled vehicles is critically dependent on the use of highly effective catalytic control systems and proper vehicle maintenance. In fact, it is possible that methanol vehicles would be more sensitive to proper maintenance than gasoline vehicles. Injector fouling and cold starting difficulties with methanol prototypes have been common problems. Although engineering improvements are being made, starting difficulties could eventually affect the reliability of methanol-fueled vehicles in customer service.

Low mileage test results for several prototype methanol vehicles have demonstrated very low hydrocarbon emissions relative to the current certification standards. These test results have generated considerable excitement about the prospects for methanol fuel to contribute to reduced air pollution levels. However, careful analysis of the data indicates that the lowest demonstrated emission levels with methanol are always associated with advanced catalytic control systems that would be equally effective when installed on gasoline vehicles. Our analysis indicates that the most optimistic assumptions for methanol-fueled vehicles that can be supported technically show methanol to have a slight hydrocarbon emissions advantage and a significant disadvantage for NOx emissions.

There could be some reduction in evaporative emissions associated with methanol use (especially if it is M100). However, evaporative emissions could also be higher if motorists are able to switch back and forth between gasoline and methanol with "fuel flexible vehicles". Refueling emissions could be significantly increased for M85 vehicles because almost double the volume of fuel is required for equivalent driving distance.

The estimated emissions characteristics for methanol-fueled vehicles assumed in the recently completed study which CMU conducted for the ARB were not consistent with the available data base. For example, the CMU study was based on ARB's assumption that M100 vehicles would emit zero non-methane hydrocarbons. In addition, one of the scenarios modelled by CMU used ARB's assumption that the formaldehyde emissions of M100 passenger cars could be controlled to 3 mg/mi in customer service, more than 90% below the level of formaldehyde control being achieved with perfectly maintained prototype vehicles. Contrary to the data showing consistently higher NOx emissions, the CMU study is also based on the assumption that NOx emissions from methanol-fueled vehicles are just as low as from advanced technology gasoline-fueled vehicles.

In addition to the emission reductions assumed for the use of methanol in light-duty vehicles, the CMU study was based on similarly optimistic assumptions regarding the emissions from methanol-fueled heavy-duty trucks. It also appears as though an assumption was made that interstate trucks would be using methanol fuel. Despite the many years of lead time required to design, develop and certify methanol-fueled motor vehicles, the CMU study is based on the unrealistic

assumption that all new motor vehicles will be capable of using methanol beginning with the 1990 model year.

The CMU study is also based on the assumption that all refineries in Southern California will be shut down if motor vehicles are converted to methanol fuel (even though it might still be economical to operate the refineries to produce jet fuel, aviation gasoline, fuel oils, lube oils, and petrochemicals, as well as gasoline and Diesel fuel for use elsewhere in California, Arizona, Nevada, Oregon, Washington, and other states and countries.) In addition, the CMU study is based on the assumption that off-road vehicles (for which the economies of scale would make methanol conversion very expensive) will begin using methanol fuel in the immediate future. For one scenario, CMU also used the assumption that many stationary sources would achieve significant NOx emission reductions through the use of methanol.

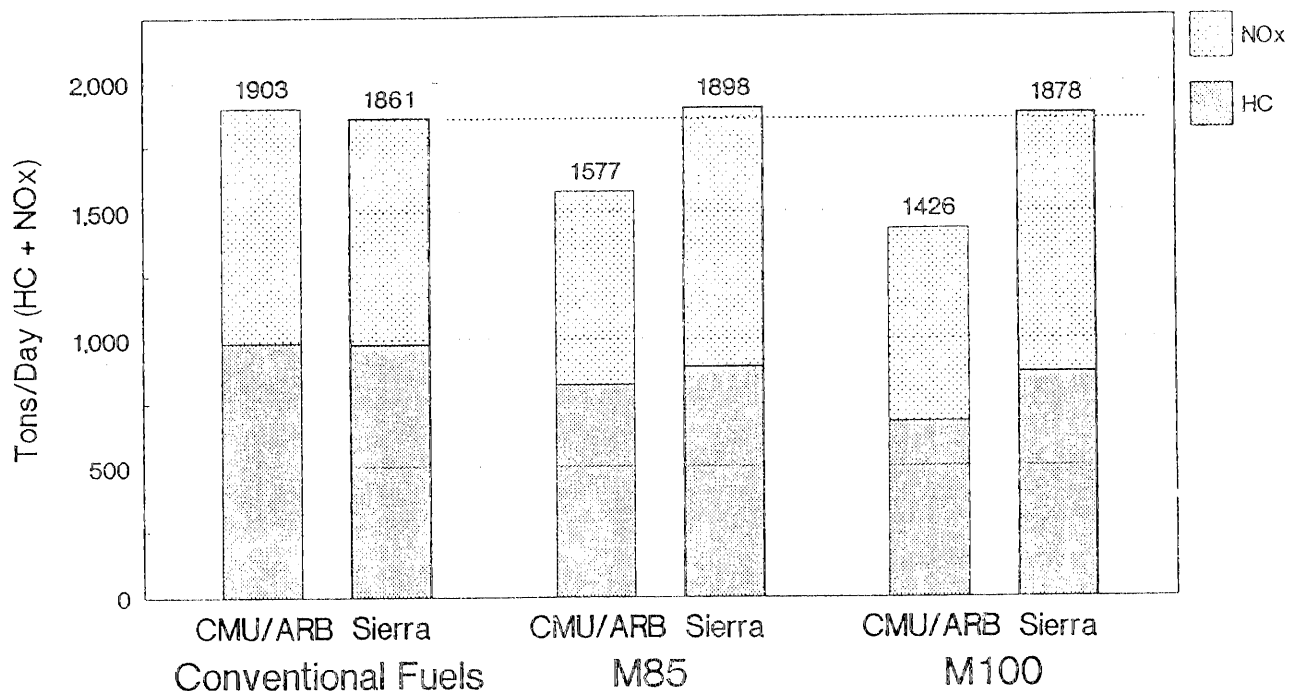
In summary, Sierra concluded that the following changes were necessary to the unrealistic set of assumptions used in the CMU study:

1. The earliest feasible date for the widespread introduction of methanol vehicles was assumed to be 1995 instead of 1990.
2. Instead of zero, methanol vehicle NMHC emissions were assumed to be 50% lower than "advanced technology" gasoline vehicle emissions.
3. Consistent with the available data base, methanol vehicle NOx emission factors were set at twice the levels projected for advanced technology gasoline vehicles. Methanol/Diesel vehicles were assumed to have NOx emissions equivalent to those of advanced technology conventionally fueled vehicles (where gasoline engines can be used).
4. Off-road vehicles were not assumed to achieve emission reductions as a result of conversion to methanol for the foreseeable future.
5. Refineries were projected to continue in operation regardless of whether methanol fuel is introduced.
6. Other stationary sources were not assumed to achieve emission reductions as a result of conversion to methanol.

By correcting the completely unrealistic emission factors used by CMU, Sierra has made substantially different projections of the effects of methanol fuel use. The effects of these different emission forecasts are illustrated in Figure 3. As the figure shows, Sierra projects that there would be no change in the ozone precursors (HC plus NOx) associated with a shift to either 85% methanol/15% gasoline (M85) or M100 fuel. Total hydrocarbon emissions are projected to be slightly lower with methanol fuel, but NOx emissions are projected to be

Figure 3

### Year 2010 Emission Projections CMU/ARB vs. Sierra Assumptions for Alternative Strategies



higher. In contrast, the assumptions used by CMU lead to the conclusion that NOx plus HC emissions would be reduced by as much as 25%.

Based on Sierra's analysis of the available data base, the benefits claimed for methanol fuel are based on unsupportable assumptions regarding the emissions from methanol vehicles in customer service. Therefore, the case has not been made that a substantial investment in the state's limited resources to switch to methanol for air pollution control purposes would be effective in improving air quality.

The potential for air quality improvement with other alternative fuels is more difficult to quantify because of the limited data base. However, natural gas and, to a lesser extent, LPG offer some potential advantages due to their lower photochemical reactivity. A problem with the available data base on these alternative fuels is that the level and caliber of the effort being devoted to research and development is substantially less than for methanol.

## Addendum

In response to the original (November 1988) version of this report, ARB has prepared and circulated written comments. ARB has objected to our comparison of methanol prototypes and certification vehicles shown above in Figure 1 claiming, "Vehicles generally used to obtain certification data are hand-built, with a large amount of engineering effort utilized to ensure that the vehicle will have the lowest possible emissions." That criticism of our work is completely without foundation and represents a serious misunderstanding of current certification practices. Build practices used for certification vehicles do not include the type of fine-tuning alluded to by ARB. Certification vehicles must represent mass-produced vehicles; they are not hand-tailored to achieve the lowest possible emissions. ARB's statement about the unrepresentative nature of certification vehicles is a more accurate description of how methanol prototypes are constructed.

Both certification gasoline vehicles and methanol prototypes receive an above-average quality of treatment during mileage accumulation. But, the gasoline-fueled certification vehicles are not allowed to receive the extraordinary maintenance that many of the methanol prototypes have received. Thus, it is the methanol vehicle emissions that are relatively lower than would be expected in customer service.

Regarding our conclusions about the significant level of reactive organic emissions from methanol vehicles, ARB has presented data for four "fuel flexible vehicles" using M85 with hydrocarbon plus formaldehyde levels ranging from 20-65% of the HC emissions from the same vehicle running on gasoline. Given the minimal mileage accumulated on these vehicles (only one above 10,000 miles), the data would appear to support our position that reactive organic emissions from methanol-fueled vehicles are substantial. With only 15,000 accumulated miles, one of the test vehicles cited by ARB is emitting 0.14 g/mi. Comparable performance has been demonstrated for gasoline vehicles. We disagree with the implication of ARB's remarks that the performance of FFVs on gasoline should be considered representative of the best available gasoline technology.

ARB's comment that "...neither EPA nor ARB have measured significant HC levels in M100 tests..." implies that Sierra's statement about significant NMHC levels in the exhaust of methanol vehicles is wrong. In fact, until just recently, EPA and ARB haven't even been measuring HC from M100 vehicles. In commenting on our report, ARB presented new data showing relatively low NMHC levels from a vehicle running on

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\* "California Air Resources Board (ARB) Response to the Sierra Research Report Entitled "Potential Emissions and Air Quality Effects of Alternative Fuels," Attachment to Letter from ARB Deputy Executive Officer, Tom Cackette to Dr. Alan Lloyd, Chief Scientist, South Coast Air Quality Management District, February 9, 1989.

M100. However, critical information regarding mileage accumulation on the catalyst was not provided.

Regarding formaldehyde emissions, ARB has disagreed with our conclusion that formaldehyde from methanol vehicles will never be as low as from gasoline vehicles using comparable emissions control systems. ARB cites data from a Toyota prototype as somehow disputing our position. However, the only methanol vehicles we are aware of that have formaldehyde emissions comparable to gasoline vehicles generally have higher NOx emissions and low-mileage catalysts. ARB's comments do not disclose the NOx emissions and catalyst mileage on the vehicle they cite as disputing our conclusions regarding formaldehyde.

After having reviewed all of ARB's comments on our report, Sierra continues to believe that the estimated emissions from methanol-fueled vehicles have been substantially underestimated in the air quality modeling studies sponsored by ARB.

###

## 2. INTRODUCTION

Under Assembly Bill 234, a new Advisory Board on Air Quality and Fuels has been created to evaluate alternative fuels. One of the Board's charges is to:

"Examine the relative environmental, and public health and safety impacts and tradeoffs resulting from the substitution of methanol fuel, compared to other alternative fuels, technologies, and vehicles, including... the effect on vehicular and nonvehicular emissions, ambient air quality, and visibility."

Depending on how the results of a recent study by Carnegie-Mellon University are presented, it can be argued that methanol substitution is one of the most effective ozone control strategies available. However, Sierra's initial review of the study indicated that there appeared to be fundamental problems with several of the assumptions on which the methanol scenarios investigated by CMU are based. First, the timing and extent of the methanol phase-in did not appear to be realistic. Second, many of the scenarios seemed to embody extremely optimistic assumptions regarding the degree of emissions control that can be expected for methanol vehicles in customer service.

For example, a complete conversion to methanol is assumed to begin with the 1990 model year. It is further assumed that methanol will be used in almost all on-road and off-road vehicles, including interstate trucks, farm equipment, construction equipment, locomotives, etc. A phase-out of oil refinery emissions was also assumed to occur. (Presumably all of the methanol is produced outside of the basin and refiners are prohibited from continuing production for export or producing jet fuel, aviation gas, fuel oil, lube oils, and petrochemicals.) One methanol scenario evaluated by CMU assumes that all vehicles will use "neat" (M100) methanol and formaldehyde emissions are assumed to be lower than from current gasoline vehicles equipped with catalysts.

If the CMU study is the only comprehensive evaluation of the potential effect of methanol conversion available to the Advisory Board, the perception may be created that there are significant air quality benefits that warrant a mandatory conversion on an accelerated schedule. To address concerns about the validity of the assumptions used, Sierra was approached by a group of energy companies and asked to review the assumptions on which the CMU study is based. Sierra proposed, and the client group approved, four tasks.

Task 1. Literature Review - Under this task, Sierra reviewed most methanol and CNG-related papers published during the last two years. Technical papers on advanced gasoline technology were also reviewed. In addition, Sierra reviewed ARB's emission factors for methanol and gasoline vehicles prepared in support of the CMU study and contained in ARB's September 1988 report on "California's Post-1987 Motor Vehicle Plan." Under the literature review task, Sierra also compiled available certification and surveillance data on gasoline and Diesel-fueled vehicles to determine the maximum degree of conventionally fueled vehicle emissions control that has already been demonstrated.

Task 2. Synthesis of Emission Factors - Based on the results of the literature review, emission factors were developed for the same basic categories selected by ARB for use in the CMU air quality modeling study.

Task 3. Development of Implementation Scenarios - Because the methanol implementation scenarios used in the CMU study did not appear realistic, Sierra developed its own estimates of the maximum feasible methanol phase-in that could be accomplished.

Task 4. Emission Modeling - Using the emission factors and implementation scenarios developed under Tasks 2 and 3, Sierra modified ARB's emissions simulation model (EMFAC) to reflect the various alternatives evaluated. The future year emissions estimates based on our own emission factors and phase-in schedules were then compared to the scenarios used by CMU.

#### Organization of the Report

Following this brief introductory section, Section 3 contains a discussion of the emission characteristics for gasoline and three different alternative fuels (methanol, CNG, and LPG) for light-duty motor vehicles. Section 4 covers the application of alternative fuels to heavy-duty vehicles. Section 5 describes the implementation scenarios for alternatives to gasoline that were used in the recently completed CMU study and in this study. Section 6 presents the emission estimates associated with the alternative implementation strategies. Section 7 presents the results of our analysis of how these different strategies would affect future year emission levels. Finally, Section 8 contains a list of references used during the course of the study.

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### 3. EMISSION CHARACTERISTICS OF ALTERNATIVE FUELS FOR LIGHT-DUTY VEHICLES

Gasoline and Diesel fuel are complex blends of hydrocarbon molecules distilled and refined from crude oil. To varying degrees, these hydrocarbon molecules are photochemically reactive and, if emitted to the atmosphere, they contribute to ozone formation. Alternatives to gasoline and Diesel currently under consideration as motor vehicle fuels include methanol, compressed natural gas (CNG), and Liquified Petroleum Gas (LPG).

Methanol, CNG, and LPG are sometimes referred to as "clean fuels". Although there are no formal guidelines for what constitutes a "clean fuel", the use of this designation seems to be related to the effect that unburned fuel emissions would have on air quality. In addition, some fuels are considered to be "cleaner burning" than others.

If the air pollution impact of motor vehicle fuel were limited to just spraying unburned fuel into the air, natural gas would be considered an inherently "clean fuel". Because natural gas is primarily methane ( $\text{CH}_4$ ), it would not significantly contribute to ozone formation or secondary particulate. Methanol ( $\text{CH}_4\text{O}$ ) and LPG (primarily propane and butane) are photochemically reactive, but less so than gasoline or Diesel fuel.

Despite the significant differences in the photochemical reactivity of different fuels, classifying a fuel as "clean" based on its chemical properties is of questionable value. The only meaningful way to evaluate the relative merits of alternative fuels is to compare the emissions from vehicles using the fuels. Without the use of emission control systems, vehicles using "clean fuels" can emit substantial quantities of harmful pollutants. During the combustion process, pollutants are formed that did not exist in the fuel. The combination of combustion temperature and nitrogen concentration in the immediate vicinity of the flame creates oxides of nitrogen ( $\text{NO}_x$ ) emissions. Incomplete combustion results in carbon monoxide ( $\text{CO}$ ) emissions. Incomplete combustion also results in unburned fuel emissions and the emissions of compounds, like formaldehyde ( $\text{CH}_2\text{O}$ ), that are created during the combustion process.

The amount of pollutants created by an engine is a function of the nature of the combustion process as well as the nature of the fuel. Regardless of the fuel that is used, lean burn, spark ignition engines can emit high concentrations of unburned fuel and generate exhaust gas that is not as suitable for catalytic treatment of  $\text{NO}_x$ . Direct injection, compression ignition engines tend to generate high levels

of particulate emissions on any compression ignition fuel. (Gasoline combustion in compression ignition engines generates substantial levels of exhaust particulate, just as Diesel fuel combustion does.) In contrast, external combustion engines, such as Rankine cycle (steam) engines emit relatively low levels of particulate even when using Diesel fuel.

The characteristics of the fuel itself do affect the emissions from the engine. For example, natural gas combustion tends to yield very low levels of non-methane hydrocarbons because the fuel itself is almost all methane. Methanol also tends to have reduced levels of non-methane hydrocarbons, but relatively high levels of formaldehyde generation are associated with methanol combustion. Gasoline combustion is more prone to non-methane hydrocarbon emissions, but formaldehyde emission rates are lower. Methanol also burns with a lower flame temperature than gasoline, which tends to reduce the generation of NOx emissions. (However, the high octane of methanol encourages the use of higher compression ratios, which in turn lead to higher combustion temperatures and higher NOx emissions.)

Fuel characteristics are also a factor in evaporative emissions. Because gasoline has relatively high vapor pressure and relatively high photochemical reactivity, evaporation must be effectively controlled to minimize adverse air pollution consequences. At the other extreme, Diesel fuel has such low volatility that evaporative emissions are not a concern. Being a gas, CNG already requires vapor tight storage; however, any leakage that might occur would not have adverse air pollution consequences. Methanol and LPG are in between these two extremes. Methanol is less volatile and less reactive than gasoline, but more volatile than Diesel fuel and more reactive than natural gas. LPG is also more reactive than natural gas.

#### Demonstrated Levels of Emissions Control

Gasoline - Efforts to control emissions from gasoline-fueled motor vehicles began during the 1950's after Professor A.J. Haagen-Smit published the results of his research indicating that hydrocarbons and oxides of nitrogen reacting together in the presence of sunlight, were the source of "smog" in Southern California. Since then, substantial progress has been made in controlling emissions from gasoline engines.

Since the implementation of exhaust emissions standards for passenger cars in the 1966 model year, California's 1989 model year emission standards have required exhaust hydrocarbon emissions from new cars to be reduced from about 9 g/mi to 0.41 g/mi.<sup>23</sup> The current standards also require carbon monoxide to be reduced from uncontrolled levels of almost 90 g/mi to 7.0 g/mi. The current NOx standards require half of each manufacturer's production to meet a 0.4 g/mi standard and half to meet 0.7 g/mi. Before controls, passenger car NOx emission levels were about 3.6 g/mi. Control of evaporative and crankcase emissions are also required. Prior to the imposition of controls the total hydrocarbon emissions from evaporation and crankcase blowby gases were in the range of 6.5 g/mi.<sup>24</sup> Table 1 summarizes the current passenger

car emission standards. Similar levels of control are required for gasoline-fueled light-duty trucks. Somewhat less stringent standards apply to medium and heavy-duty gasoline-fueled vehicles.

Table 1

1989 Model Year Emission Standards  
For Gasoline-Fueled Passenger Cars

	----- grams/mile -----			
	HC	NMHC	CO	NOx
Exhaust Emissions *	0.41	0.39	7.0	0.4/0.7
Evaporative Emissions	0.14	0.14	n.a.	n.a.
Crankcase Emissions	0.00	0.00	0.0	0.0
Total Controlled Emissions	0.55	0.53	7.0	0.7

\* calculated based on assumed 50/50 split of diurnal and hot soak emissions under 2.0 g/test standard, 3.05 hot starts/day, and 30 miles/day.

note: "n.a." means not applicable.

The single most effective automotive exhaust emission control device that has been developed over the last thirty years is the catalytic converter. However, over half of the reductions that have been achieved are associated with non-catalytic control approaches. These include revised combustion chamber geometry, improved ignition systems, improved fuel metering systems, techniques to reduce fuel enrichment during cold start and warmup, air injection, and exhaust gas recirculation. The complexity of exhaust emission control systems is further increased by the fact that exhaust controls must interface with evaporative emissions and crankcase emissions controls.

Although significant design differences exist between current model passenger cars, the major elements of the exhaust emissions control system used on the "typical" new car are as follows:

1. a combustion chamber designed for low "engine out" hydrocarbon emission levels,
2. a "high energy" ignition system designed for consistent mixture ignition and long spark plug life,
3. a "multiport" fuel injection system designed for accurate fuel metering with minimum needs for fuel enrichment during cold starting,

4. an oxygen sensor and feedback (computer) control system to maintain air/fuel ratio at the chemically correct ratio needed for best catalyst performance,
5. a 3-way catalyst to provide simultaneous reductions of HC, CO, and NOx emissions, and
6. an EGR system with flow proportional to engine load to reduce NOx emissions without significantly affecting HC emissions or driveability.

When properly maintained, gasoline vehicles can achieve emission levels that are below the current emission standards to varying degrees. Figures 4 and 5 illustrate some of the lowest emission levels being achieved by a wide range of vehicle manufacturers. All of the results shown in these figures were calculated from the official certification test results published by EPA. They include the "deterioration factor" established from a 50,000 mile durability test. (Final certification values are established by testing "data" vehicles after 4,000 miles of operation and then multiplying the 4,000 mile test results by the "deterioration factor" established by the durability vehicles to project the results to 50,000 miles.) A 0.85 adjustment factor has been used to convert hydrocarbon emissions to a non-methane basis.

Figure 4

### Gasoline Vehicle Hydrocarbon Emissions for Selected 1988 Models

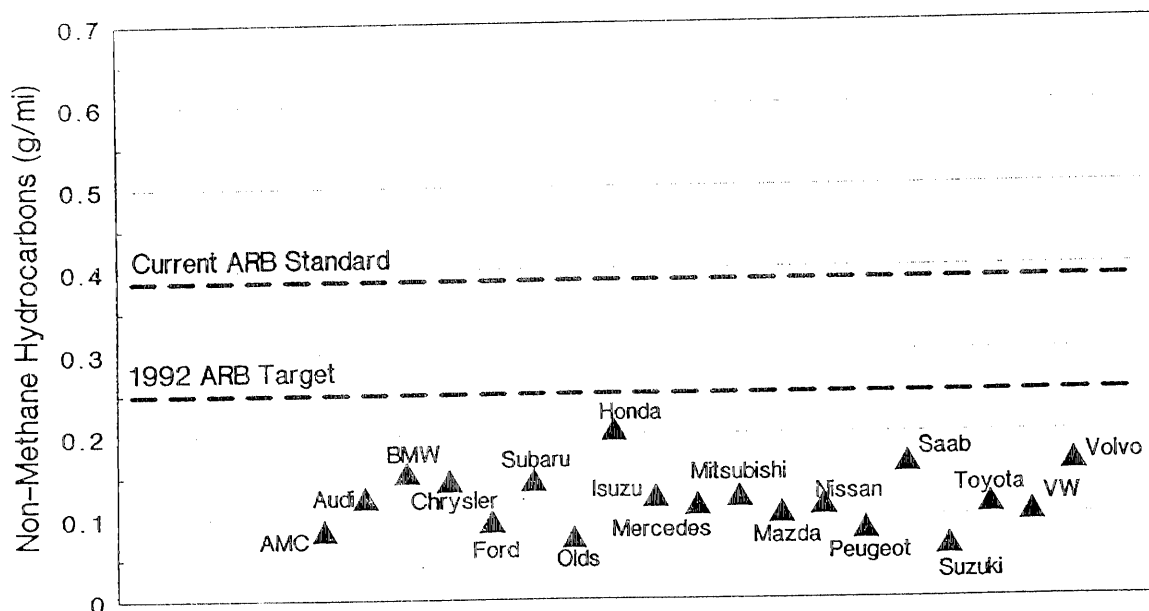
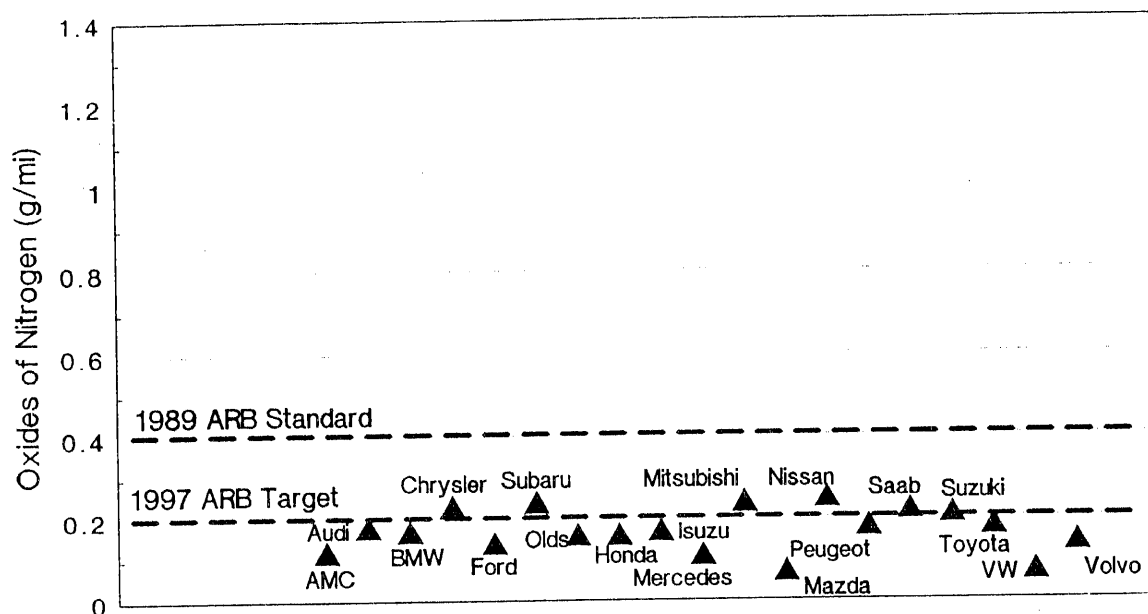


Figure 5

## Gasoline Vehicle NOx Emissions for Selected 1988 Models



As shown in Figure 4, a number of vehicles have been certified to hydrocarbon emission levels that are well below the current standard of 0.39 g/mi non-methane hydrocarbons (NMHC). In addition, these vehicles are below the 0.25 g/mi standard that the ARB staff is proposing for the 1992 model year.<sup>8</sup> As shown in Figure 5, much lower NOx emission levels have been achieved than are required by the current standard. The best vehicles are also below the 0.4 g/mi standard that will be phased-in beginning with the 1989 model year. In addition, several models are already certified below the 0.2 g/mi NOx level that ARB hopes to establish as a standard for the 1997 model year.<sup>8</sup> The emissions results plotted in Figures 4 and 5 represent some of the lowest emission vehicles currently certified. Other models are much closer to the emission standards. However, differences between the performance of gasoline vehicles can be traced to differences in their emission control systems. The cleanest vehicles tend to have multiport fuel injection and the largest amount of platinum group metals in their catalysts.

Based on characterization testing performed during the 1970s, formaldehyde emissions from gasoline-fueled vehicles are not a particular concern. EPA test results on 12 non-catalyst vehicles indicated average formaldehyde emissions to be 30 mg/mi.<sup>9</sup> Tests of eight catalyst-equipped vehicles indicated formaldehyde levels below 10 mg/mi.<sup>9</sup>

Methanol - Hydrocarbon and NOx emissions for a number of methanol prototypes tested by ARB<sup>2</sup> are plotted in Figures 6 and 7. The ARB

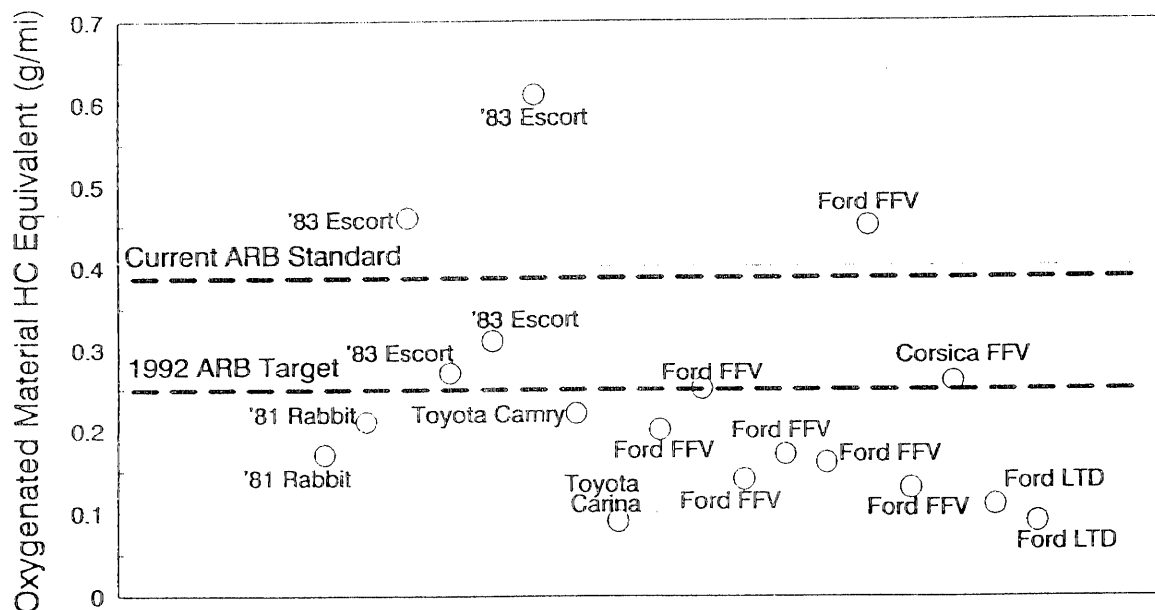
methanol test fleet consists of one (1) 1981 Rabbit; two (2) 1983 Escorts with carburetors; three (3) 1983 Escorts with fuel injection; one (1) 1985 Toyota Camry; one (1) 1986 Toyota Carina; seven (7) 1987 FFV Crown Victorias; and one (1) 1988 FFV Corsica.

As shown in Figure 6, a wide variation in "hydrocarbon" emissions has been observed using the EPA-recommended method for reporting all measured organic materials as if they contained only carbon and hydrogen in the ratio of 1:1.85. Under the EPA scheme, organic emissions for methanol-fueled vehicles are reported as "organic material hydrocarbon equivalent" (OMHCE). The methanol fraction of total organic emissions is reduced by 57% to account for the fact that 57% of the weight of methanol is oxygen and "extra" hydrogen atoms. The "adjusted" methanol value is added to the full-weight of the non-oxygenated hydrocarbon emissions.

ARB is one of the few places where efforts have been made to measure the non-oxygenated hydrocarbon emissions (such as NMHC) in the exhaust of methanol vehicles. Although very low NMHC levels have been measured on low mileage vehicles, a number of the methanol prototypes emitted relatively high quantities of NMHC once they had accumulated more mileage. On M85 fuel, several Ford Escorts have been measured at 0.2-0.4 g/mi NMHC. FFV Ford Crown Victorias and a Chevrolet Corsica have been measured at about 0.1 g/mi NMHC at low mileage. A Toyota

Figure 6

### Low Mileage ARB Test Results for Methanol Vehicle Hydrocarbon (OMHCE) Emissions



Notes : Methanol vehicle emissions are based on Organic Material Hydrocarbon Equivalent "OMHCE" technique recommended by EPA.

Camry was 0.67 g/mi without the catalyst and 0.1 g/mi with catalyst with less than 20,000 miles. This is one of the few test results without a catalyst available from ARB.

In general, the NO<sub>x</sub> emission levels are much higher than the best of the late-model gasoline vehicles shown above. The two vehicles labeled "Ford LTD" are dedicated methanol prototypes. As shown in Figure 7, the vehicles were below 0.4 g/mi when tested by ARB but they only had accumulated about 2500 miles.

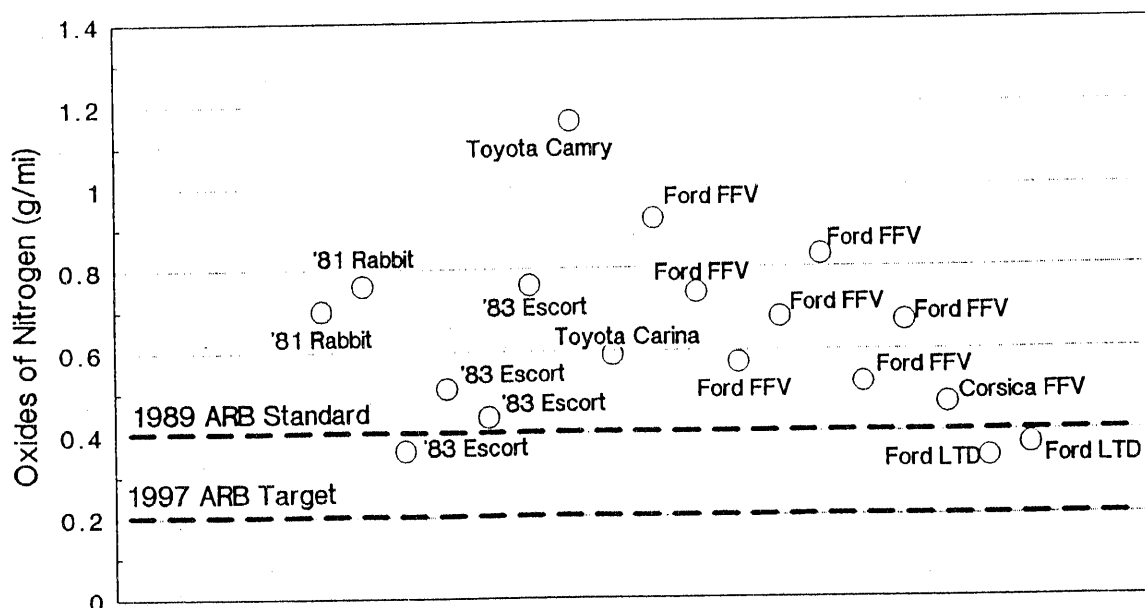
Little data are available to characterize the NMHC emissions of M100 vehicles. ARB has a policy of not testing M100 vehicles, and EPA does not yet measure the NMHC levels of any methanol vehicles. The result is that there is a clear data gap for the NMHC levels for M100 vehicles. The only information available at this time the emissions data reported by vehicle manufacturers in the literature.

Fouled fuel injectors have been a persistent problem with the vehicles tested by ARB. The emission levels reported in Figures 6 and 7 reflect numerous injector replacements. (Injectors have been changed in all of the 1987 FFV Fords, the 1983 Escorts, both Toyotas, and the 1988 Corsica.) In addition, the ARB data are primarily for low mileage vehicles. Only one of the tested vehicles was beyond 30,000 miles. That vehicle, a 1981 VW Rabbit, was a gross emitter.

In general, severe deterioration of emissions control has been observed for all vehicles. However, the vehicles receive extraordinary maintenance to keep their emission levels as low as

Figure 7

### Low Mileage ARB Test Results for Methanol Vehicle NO<sub>x</sub> Emissions



possible. In addition to the fuel injector problems, deterioration of the Escort fleet led Ford to provide new catalytic converters, EGR valves, and oxygen sensors as well. Fuel pump failures have also been a common problem. It is expected that these types of failures can be eliminated through further development work.

Because formaldehyde is readily formed by the partial oxidation of methanol, it is not surprising that methanol-fueled vehicles emit significantly more formaldehyde than gasoline-fueled vehicles. The grams per mile are a function of the fuel consumption (weight and engine size) of the vehicle. For a mid-size vehicle, uncontrolled formaldehyde levels on M85 are approximately 0.4 g/mi (400 mg/mi). With a fresh catalyst, formaldehyde emissions can be temporarily controlled to 15 mg/mi or less. However, as soon as a few thousand miles have been accumulated on the catalyst, tailpipe levels rise to about 35 mg/mi for larger vehicles like the Ford Crown Victoria<sup>5</sup>. Smaller vehicles may emit at half of this level with the same catalyst efficiency.

ARB's test results for formaldehyde have been quite variable from car-to-car and from test-to-test of the same car. How much of this variability is due to sampling problems is not clear; however, condensation is an expected problem with some of ARB's tests that have been run without heated sample lines. Chevron reports<sup>10</sup> even with heated sample lines some condensation may occur upstream of the sample collection point and measures such as washing the condensate into the sample are necessary to ensure that all of the formaldehyde emissions are captured for analysis.

On the FFV Escorts, Ford measured "engine-out" formaldehyde emissions of 0.178 g/mi on M85 vs. 0.249 g/mi on M100. These results are consistent with the tailpipe emission measurements Ford obtained with 50,000 mile catalysts: 50 mg/mi for M85 vs. 69 mg/mi for M100. Similar results were measured on the FFV Crown Victorias. Engine-out formaldehyde was 0.44 g/mi on M85 vs. 0.65 g/mi on M100. EPA reported engine-out formaldehyde emission levels of 300-600 mg/mi for a prototype LCS-M (Lean Combustion System - Methanol) Toyota Carina.<sup>11</sup>

Compressed Natural Gas (CNG) - Natural gas has several physical and combustion properties that distinguish it from gasoline. As a gaseous fuel it does not require any of the heat needed to transform liquid fuel to a vapor so that a combustible mixture can be formed. This means that the function of the carburetor is simplified to mixing fuel and air. Because there is no need to vaporize CNG there is also no need to enrich the mixture under cold start conditions to ensure that a combustible mixture can be formed. Thus, engines operating on CNG will always have leaner operation under cold start conditions and lower "engine out" HC and CO emission levels than comparable gasoline or methanol-fueled engines.

A disadvantage of gaseous fuels is that they take up more volume inside the engine and reduce an engine's volumetric efficiency. Thus, a gasoline engine modified to operate as a dual fuel vehicle will exhibit comparatively poor performance and fuel economy while

operating on natural gas. Another feature of natural gas is that it has a lower flame speed than gasoline. This means that the combustion process takes longer, the peak cylinder pressure is reduced and that efficiency and power are lost. A recent Ford paper indicates that a performance loss of up to 15 percent can be expected in a gasoline vehicle operating on CNG. One option to offset the power loss associated with the lower flame speed of CNG is to advance the spark timing. Advancing the spark timing, however, has the disadvantage of increasing NOx and HC production. Studies have shown that gasoline engines that have the spark timing adjusted to account for the lower flame speed of natural gas produce slightly higher HC levels, no change in CO and significant increases in NOx.

Another option to improve the performance and efficiency of CNG use is to increase the compression ratio of the engine. CNG's high octane levels (roughly 120 Research and Motor Octane Number) can support compression ratios as high as 16:1 without knock problems. Recent single cylinder engine studies by DOE<sup>12</sup> have shown that the highest thermal efficiency (on the order of 50 percent) was achieved at a compression ratio of 15.5:1. An evaluation of the emission levels at higher compression ratios indicated the following:

- There was no clear and consistent trend of changing HC emissions with changing compression ratio, except that the higher compression ratios (up to 18.5:1) produced more HC than the baseline (8.4:1). Another finding, from the perspective of HC, was that the optimum equivalence ratio appeared to be in the range of .75 to .80 (defined on the basis of the ratio of fuel to air). It also appeared that HC levels increased rapidly as the air/fuel mixture approached the lean limit.
- CO emissions were not significantly affected by compression ratio and are primarily a function of the equivalence ratio.
- No consistent trend in the sensitivity of NOx emissions to the compression ratio was found except at equivalence ratios near the lean limit. At equivalence ratios in the range of .65 to .75, NOx emissions for higher compression ratios were significantly higher than those of the baseline case.
- The study also noted that aldehyde emissions were quite low for all of the conditions tested.

The study concluded that from the perspective of thermal efficiency and HC, CO and NOx emissions, the optimum equivalence ratio for natural gas operation appears to be in the range of .75 to .8. These results indicate that two potential emission issues could emerge from using a spark-ignition engine optimized for natural gas operation. The first is that total HC levels are likely to be above federal total HC standards, however, they should have little trouble achieving California's non-methane HC standard. The second and more significant issue is the elevated NOx levels associated with lean operation at elevated compression ratios. The primary options available to control

the elevated NOx levels are (1) the operation of the engine at leaner conditions; (2) the use of exhaust gas recirculation; (3) the use of three-way catalysts to catalytically reduce NOx. The first option is undesirable because it would increase HC and degrade driveability. The effect of the second is unknown as little research in this area has been conducted. The catalytic NOx control approach is incompatible with lean operation. The only way that the third option could be pursued is with combustion maintained at stoichiometry as in current gasoline engines. This approach, however, would reduce efficiency because the air/fuel ratio would be moved away from the optimal lean operating conditions.

With the exception of specially equipped 1984 Ford Ranger pickup trucks, all emissions data for CNG fueled light duty vehicles are based on gasoline vehicles that have been converted either to dedicated CNG vehicles or dual fuel vehicles. In all cases the conversions are based on equipment developed by firms outside of the auto industry. None of the vehicles, including the Ranger pickups, have been completely optimized for CNG.

The earliest data found to provide a gasoline to CNG comparison on the basis of the Federal Test Procedure (FTP) was developed by EPA in 1973.<sup>13</sup> As shown in Table 2, tests were conducted for a 1972 Chevrolet Nova equipped with an automatic transmission and a 250 cubic inch displacement (CID) engine. The pre-catalyst vehicle had been converted to dual-fuel operation and was capable of operating on either gasoline or CNG. The results, averaged over the two tests for each fuel, indicated that the use of CNG provided significant reductions in all three of the regulated pollutants.

Table 2

Test Results for a 1972 Chevrolet Nova  
FTP Emissions (gm/mi)

<u>Fuel</u>	<u>THC</u>	<u>CO</u>	<u>NOx</u>
Gasoline	1.41	6.27	3.70
CNG	0.89	1.57	1.92

As would be expected, the CNG CO levels are substantially lower than the comparable gasoline engine results reflecting the cold start advantage of gaseous fuels over gasoline. With a 1972 model vehicle as the baseline, there were also significant reductions in total hydrocarbon (THC) and NOx emissions. The hydrocarbon emission reduction is more significant than indicated by the above data because of the expected high fraction of methane.

CNG test results with emission control systems are shown in Table 3, which contains data for selected dual fueled vehicles tested by the ARB. The results indicate that CNG operation results in substantially higher THC levels (up to 6 times more) than late model vehicles operating on gasoline. On the other hand, the NMHC levels on natural gas were generally lower. The CO levels were much lower on natural gas, and NOx emissions were also lower ( $\leq 0.4$  g/mi).

Table 3

Emission Test Results<sup>14</sup> For California Light-Duty Vehicles  
Converted by Dual Fuel Systems, Inc.

Vehicle	FTP Emissions (gm/mi)							
	Gasoline				Natural Gas			
	HC	NMHC	CO	NOx	HC	NMHC	CO	NOx
77 200SX	0.20	0.18	6.4	0.9	1.14	0.23	0.2	0.1
80 Citation	0.32	0.28	5.4	0.7	0.69	0.09	0.2	0.3
80 LTD	0.51	0.43	7.8	0.5	1.69	0.22	0.3	0.3
81 Malibu	0.29	--	4.6	0.6	2.31	0.30	0.1	0.4
81 Dodge PU	0.34	--	5.0	1.0	2.82	0.37	2.1	0.4

Liquified Petroleum Gas (LPG) - The market for LPG vehicles in the U.S. has been confined primarily to medium and heavy-duty vehicles; little data are available to characterize the emissions performance of light-duty LPG vehicles. Conversations with staff at EPA's Ann Arbor Laboratory indicated that they have not conducted any emissions tests on light-duty LPG vehicles. Conversations with the ARB indicated that no original equipment manufacturers (OEM's) have certified light-duty LPG vehicles for sale in California. Several aftermarket manufacturers, however, have developed conversion kits to alter existing gasoline-powered vehicles to operate on LPG. Approximately 90 percent of these conversions allow the vehicle to operate on either gasoline or LPG.

The conversion kits do not alter the spark advance or compression ratio of the engine. Therefore, when operating on LPG the engines experience a loss in power (roughly 10 percent is quoted in the literature). All conversion kits must be certified for sale in

California. In order to qualify for certification the aftermarket manufacturers must demonstrate to ARB that the converted vehicle achieves the same emission levels as the base gasoline engine and those levels must be within the applicable emission standards. ARB conducts independent tests on approximately 80 percent of the certification applications for these vehicles. These test results are the primary source of emissions information for LPG vehicles.

Conversion kits have been successfully applied to a wide range of carbureted and fuel injected vehicles with open and closed loop control systems. A summary of the emission levels recorded for two passenger cars is presented in Table 4. Both vehicles are equipped with a three-way catalyst and a closed loop fuel control system.

Table 4  
Emission Test Results  
For Selected Passenger Cars  
(Federal Test Procedure)

<u>Test Vehicle</u>	<u>Test Fuel</u>	<u>Exhaust Emissions (g/mi)</u>			
		<u>THC</u>	<u>NMHC</u>	<u>CO</u>	<u>NOx</u>
1984 Ford	LPG	0.37	--	0.8	0.1
1985 Plymouth	LPG	0.30	--	6.6	0.6
	LPG	0.34	--	6.1	0.6
Emissions Standards		0.41	0.39	7.0	0.7

The results indicate relatively low THC levels and wide variation in the CO and NOx levels. These variations are not uncommon for converted gaseous fueled vehicles and indicate the sensitivity of the results to emissions and driveability calibrations. It should be noted that these vehicles were operated under closed-loop controls typical of a gasoline engine and that no attempt was made to adjust them for lean operation.

Table 5 displays the results for selected light-duty pickup trucks equipped with three-way catalysts and closed loop fuel control systems. The results indicate that these vehicles had no problem certifying to any of the applicable emission standards.

Table 5  
Emission Test Results  
For Selected Light-Duty Trucks  
(Federal Test Procedure)

<u>Test Vehicle</u>	<u>Test Fuel</u>	Exhaust Emissions (g/mi)			
		<u>THC</u>	<u>NMHC</u>	<u>CO</u>	<u>NOx</u>
1984 Ford	LPG	0.42	--	2.56	0.36
Emissions Standards			0.50	9.00	1.00
1985 Toyota	LPG	0.12	--	1.10	0.44
	LPG	0.17	--	3.94	0.58
Emissions Standards			0.39	9.00	1.00

It should be noted that all of the results presented are based on vehicles that have not been optimized for performance. The two primary options available to offset the power loss due to the lower flame speed of LPG are the same as those discussed for CNG: advance the spark timing; and increase the compression ratio of the engine. Sierra is unaware of any data characterizing the emissions performance of either option. The emissions effects of both options, however, would be expected to increase NOx and HC production.

### Potential for Further Control

Several different approaches are available to increase the efficiency of controlling exhaust emissions with catalytic converters. These include increased catalyst loading and system changes to reduce the time required for the catalyst to reach normal operating temperature. Both of these techniques are applicable to gasoline, methanol, CNG, and LPG fueled vehicles. During the critical period before the catalyst system reaches operating temperature, there are techniques available to further reduce "engine-out" emission levels through fuel modification or temporary hydrocarbon emissions storage.

Increased Catalyst Loading - The principal active ingredients of three-way catalysts are platinum and rhodium. Platinum is the ingredient which is principally responsible for the control of hydrocarbons and carbon monoxide. Rhodium is the ingredient which is principally responsible for the control of NOx. The amount of rhodium used in three-way catalysts has a significant effect on the ability of the catalyst to eliminate NOx. This relationship has been clearly established from laboratory tests<sup>15</sup> as well as from the analysis of hundreds of tests of certification vehicles.<sup>16, 17</sup> A 1986 ARB study indicated that having at least 0.68 grams of rhodium loading increases the probability of certification to a 0.4 g/mi NOx standard. An earlier study that Sierra performed for OTA<sup>18</sup> indicated that having at least 4 grams of platinum substantially improves the chances of achieving HC emissions below the 0.41 g/mi standard.

Start Catalysts - One means of solving the catalyst warmup problem is through the addition of a small volume "close-coupled" catalyst. Small catalysts located as close as possible to the outlet of the exhaust manifold are referred to as "start catalysts", "pre-catalysts", or "warm-up catalysts". The concept is straightforward:

- locate a catalyst as close to the exhaust valve as possible to minimize heat loss;
- use a monolithic design to minimize warmup time; and
- make the size of the catalyst only as large as is necessary to handle the exhaust volume that occurs under warmup conditions to minimize thermal inertia.

Data from tests run by Chrysler and previously reported by EPA<sup>15</sup> demonstrate the potential of start catalyst installations to reduce hydrocarbon and carbon monoxide emissions by approximately 50%. Some start catalyst systems have been used on production vehicles. However, excessive deterioration due to the exposure to high temperatures that results from the close-coupling of the converter has been a problem. Ideally, the start catalyst would be bypassed as soon as the main catalyst has reached operating temperature. Such a bypassable start catalyst system was developed by General Motors during the early 1970s, but the emission standards were eventually met

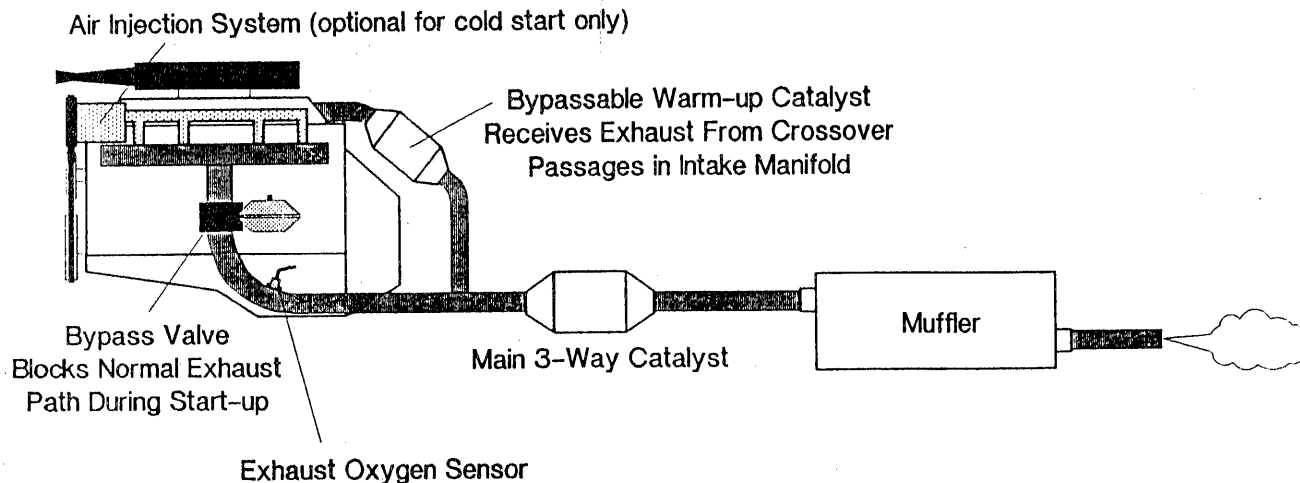
without the need for the system and it was never introduced into production.

In the system developed by GM, a heat riser-type valve in the exhaust system is closed during cold starting, thereby forcing all exhaust gases into the heat-riser passages of the intake manifold. A separate exhaust outlet is provided at the back of the intake manifold and a small volume start catalyst is mounted as close as possible to the outlet. Exhaust gases pass through the start catalyst and enter the exhaust system downstream of the heat-riser valve. From there they enter the main catalyst. As soon as the main catalyst has reached operating temperature, the heat-riser valve is opened and the exhaust gases flow directly to the main catalyst, bypassing the start catalyst. A schematic of such a bypassable start catalyst system is shown in Figure 8.

Electrically Heated Catalysts - An alternative approach to achieving quick catalyst light-off involves the use of catalyst substrates that are electrically heated before engine cranking. Recent tests by EPA have shown that this technique can dramatically reduce the hydrocarbon emissions of both gasoline and methanol fueled vehicles<sup>19</sup>. With the heated catalyst, formaldehyde emissions from an M100 Volkswagen were reduced to 4-7 mg/mi from 9-13 mg/mi without heating. Total organic material, hydrocarbon equivalent (OMHCE) was reduced to 0.05-0.09 g/mi from 0.15-0.21 g/mi without heating. Similar levels of effectiveness on gasoline fueled vehicles are anticipated.

Figure 8

### Bypassable Start Catalyst System



At the present state of development, electrically heated catalysts are still at the advanced product research phase. Prototype systems for extended performance testing have not yet been developed. Durability is yet to be proven. The power demands on the system are so high ( $\approx 4\text{kW}$  for 30 seconds), that a much larger vehicle battery or a separate battery for catalyst heating would be required. The increased complexity of the system would also be expected to increase the potential for system failure in customer service. The incentive for tampering would also appear to be a significant issue because disconnection of the system could extend the starting performance of the basic engine. Despite these concerns, the potential benefits of electrically heated catalysts are so large that increased development efforts would appear to be a high priority.

Onboard Fuel Alteration - In the early 1970s, several manufacturers experimented with gasoline treatment systems to reduce start-up emissions. For example, Saab developed an on-board fuel distillation system that segregated lighter hydrocarbons from heavier material and used the lighter hydrocarbons for cold start and warm up operation. This gave the engine the benefits of gaseous fuel operation (i.e., lack of a need for mixture enrichment). As a result, hydrocarbon and carbon monoxide emissions were reduced by over 50%. Advances in catalytic emissions controls allowed all manufacturers to meet the emission standards without the use of such sophisticated control systems. As a result development work was abandoned.

Systems for starting methanol vehicles with "dissociated" fuel are analogous to the onboard distillation approach for gasoline vehicles. Unlike gasoline, methanol is a single molecule that cannot be distilled into more volatile and less volatile compounds. However, methanol can be broken down into hydrogen ( $\text{H}_2$ ) and carbon monoxide by a high temperature catalytic reaction. A system tested by EPA<sup>20</sup> involved a three step process: 1) methanol vaporization in a stainless steel boiler; 2) carrier gas ( $\text{N}_2$ ) assisted transfer of the methanol vapor through an electrically heated superheater; and 3) catalytic dissociation of superheated methanol vapor across a catalyzed silicon carbide substrate. It is apparent that dissociation systems are much more complex than distillation systems for gasoline. The commercial feasibility of dissociation systems appears to be questionable.

Hydrocarbon Storage - Evaporative hydrocarbon emissions are controlled by venting vehicle fuel systems to the atmosphere through a canister filled with activated charcoal. Hydrocarbon vapors are adsorbed onto the charcoal and subsequently purged into the engine when the vehicle is started. Air is drawn through the charcoal bed and into the intake manifold of the engine. This same concept can be employed to reduce exhaust emissions during the period before the catalyst has reached operating temperature.

Prototype systems incorporating onboard storage of start-up emissions on activated charcoal were built by General Motors and Mercedes during the early 1970s. The systems were highly effective, reducing HC emissions by more than 50%. On the GM system, the charcoal adsorber consisted of a conventional pelletized catalyst container that was

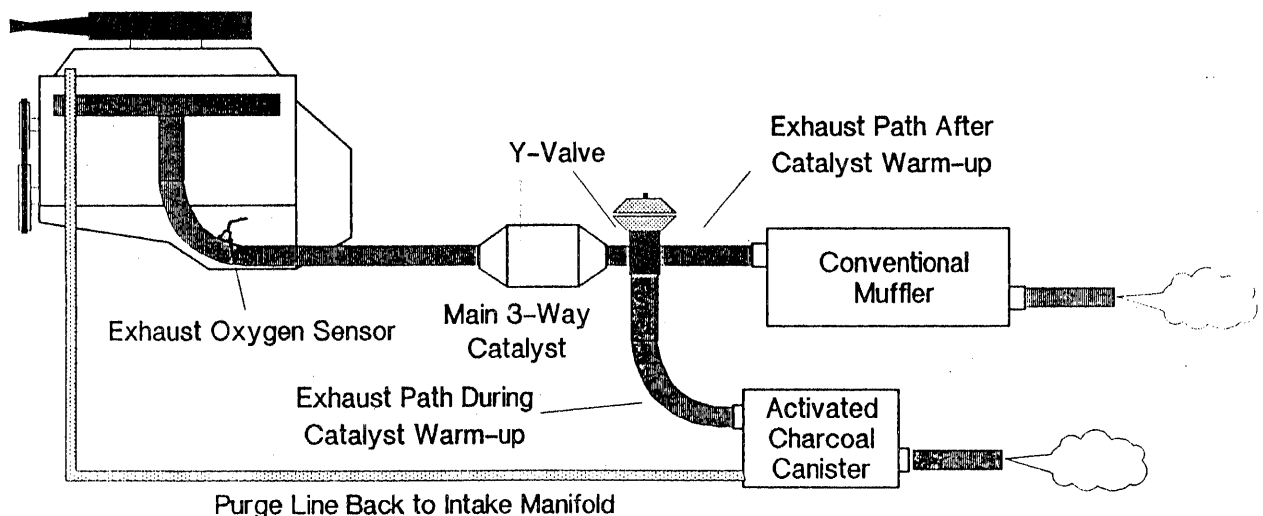
filled with activated charcoal instead of catalyst beads. The charcoal bed was located behind the catalyst so as not to interfere with catalyst warm-up. After enough time had passed for the catalyst to reach light-off temperature, the exhaust gas was diverted to by pass the charcoal bed and the hydrocarbons stored on the bed were purged in the engine. A schematic of the system is illustrated in Figure 9.

As in the case of the onboard distillation system, development work on charcoal storage was terminated when it was clear that it would not be required. In addition, there were practical concerns regarding the potential damage to the charcoal bed that would result from a failure of the valve in the exhaust system to switch the exhaust flow from the charcoal bed. The system may be less effective on methanol-fueled engines than gasoline-fueled engines because of the difficulty in purging alcohol from the activated charcoal.

Further development of supplemental control systems is clearly feasible for both gasoline and alternative fueled vehicles. However, more sophisticated control systems may be most effective in reducing emissions from gasoline-fueled vehicles.

Figure 9

### Cold Storage System



#### 4. ALTERNATIVE FUELS IN HEAVY-DUTY VEHICLES

##### Heavy-Duty Engine Emissions With Conventional Fuels

Table 6 shows how the federal emissions standards established for heavy-duty gasoline engines compare to uncontrolled emission levels. (Federal standards were recently adopted by California, in order to align California and Federal standards.) Since the implementation of exhaust emissions standards for heavy-duty gasoline engines in the 1970 model year, exhaust emission levels from new trucks have been reduced by approximately 90% for HC and CO, but prior to 1991, the standards have allowed NOx emissions to be higher than uncontrolled levels.<sup>34</sup> Reduced NOx emissions compared to uncontrolled levels will be required starting in 1991.

Table 6

##### Heavy Duty Gasoline Engine Emissions

	----- g/bhp-hr -----		
	HC	CO	NOx
Uncontrolled Emissions	10.9	155.0	6.7
1988 Federal Standards	1.1	14.4	10.6
1991 Federal Standards†	1.1	14.4	5.0
14,000+ GVW	1.9	37.1	5.0

† Engines intended for use in vehicles over 14,000 lb GVW may certify to the higher CO and HC standards. These engines may also be used in vehicles under 14,000 lb GVW, so long as the total number of such engines is no more than 5% of all engines for vehicles under 14,000 lb GVW sold by that manufacturer

Prior to 1988, the federal emissions standards for heavy-duty Diesel engines required very little control except for that needed to reduce smoke and particulate emissions. Current standards and those upcoming for 1990 and later model year vehicles are listed in Table 7.

Table 7

## Heavy Duty Diesel Engine Emissions

	---- grams/brake horsepower-hour ----			
	<u>HC</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>
Uncontrolled Emissions <sup>37</sup>	3.4	4.8	10.7	-
1988 Federal Standards	1.3	15.5	10.7	0.60
Upcoming 1990 Standards	1.3	15.5	6.0	0.60
Upcoming 1991-93 Standards	1.3	15.5	5.0	0.25*
Upcoming 1994+ Standards	1.3	15.5	5.0	0.10

\* PM limit is 0.10 g/BHP-hr for urban buses in 1991, and for all vehicles beginning in 1994.

Emissions measurements for heavy-duty Diesel engines are performed while operating the engine over the Federal Heavy-Duty Transient test cycle on an engine dynamometer. This cycle covers a range of speeds and loads which are considered representative of those experienced by heavy-duty Diesel engines in urban operation. It was originally proposed to test heavy-duty gasoline engines using the same test cycle. However, manufacturers objected that the Heavy-Duty Transient cycle was unrepresentative of normal operations for gasoline-fueled vehicles. As a result of these objections, gasoline engines were permitted to be tested using another transient emissions test cycle developed by the Motor Vehicle Manufacturer's Association (MVMA). Since the MVMA cycle is somewhat less stringent than the Heavy-Duty Transient cycle, emissions standards for gasoline engines were adjusted downward somewhat to compensate.

As originally proposed by EPA, emissions standards for heavy-duty gasoline and Diesel engines were identical, except for the Diesel particulate standard, which did not apply to gasoline engines. The proposed HC and CO limits were set at the level believed to be achievable by gasoline engines using oxidation catalysts, even though EPA recognized that Diesel engines were capable of meeting much more stringent standards. The proposed NOx standards were set to be achievable by Diesel engines, even though gasoline engines might be able to achieve much lower levels using three-way catalysts. The reason for this was to establish a "level playing field", so that one engine type would not be at a competitive disadvantage with another due to differences in emissions standards.

In its final rulemaking, EPA modified this "level playing field" approach by creating a special exemption for medium-heavy duty gasoline engines (those intended for use in trucks over 14,000 lb

GVW). Because of doubts about the feasibility of catalyst technology for these engines (combined with the perception that they constituted a small and shrinking fraction of total engine sales), EPA relaxed the HC and CO limits for these engines to levels which could be achieved without catalytic converters.

Emissions limits for light-heavy duty engines (intended for use in vehicles under 14,000 lb GVW) were kept at the catalyst-forcing level. Light heavy-duty vehicles are primarily large pickups and vans, which closely resemble light-duty trucks in characteristics. These vehicles were considered to be able to use light-duty oxidation catalyst technology. Thus, emission standards for light heavy-duty gasoline engines and all Diesel engines were intended to be equivalent, after adjusting for the differences in the stringency of the emissions cycle.

Although most light-heavy duty vehicles are mass-produced pickups and vans, a limited number of specialized vehicles are also produced in this weight range. These vehicles are often built on chassis similar to those used in larger medium-heavy trucks. In many cases, these chassis were not designed to accommodate the catalytic control systems used in the mass-produced light-heavy duty vehicles. Recognizing that it would not be economic to develop catalyst control systems solely for these vehicles, EPA permitted a limited number of light-heavy duty vehicles (up to 5% of production) to be equipped with medium-heavy duty engines.

The feasibility of achieving lower emission levels than required by the standards that have already been adopted depends on the ability of manufacturers to develop durable 3-way catalysts for heavy-duty gasoline engines and durable particulate traps for Diesel engines. Through the application of more advanced catalytic control technology, the ARB staff has recently estimated<sup>38</sup> that the standards for light-heavy-duty gasoline vehicles can be reduced by about 30% for HC, 50% for CO and about 70% for NOx. The basic position of the ARB staff, which Sierra generally agrees with, is that the level of emissions control that can be achieved from gasoline-fueled heavy-duty engines is essentially the same as can be achieved from light-duty vehicle. Given this situation, the potential benefits (or lack thereof) of alternative fuels are similar to the case for light-duty vehicles expressed earlier.

However, the situation is somewhat different for Diesel engines. The basic 1991 federal standards are at roughly the limit of the particulate emissions that can be achieved without the use of traps. For 1991 model year transit buses, and for all heavy-duty Diesels starting in 1994, the federal standards are "trap-forcing". Since traps have not yet been demonstrated to be reliable in customer service for the required minimum maintenance interval of 150,000 miles, there is some question whether the standards can be achieved with conventional engines using Diesel fuel. In addition, the 5.0 g/bhp-hr NOx emissions standard is considered to be near the limit of

Diesel engine control technology. In a recent study for the Office of Technology Assessment<sup>37</sup>, Sierra concluded:

"There is no presently demonstrated technology for achieving heavy-duty Diesel NOx emission levels less than about 4.5 g/BHP-hr without significant adverse effects on fuel economy and particulate emissions."

Given the situation for heavy-duty engines described above, it is obvious why there has been substantial interest in the use of alternative fuels for heavy-duty vehicles. The remainder of this section summarizes the capabilities of methanol, CNG, and LPG in heavy-duty engines. However, it should be noted that gasoline engines must be considered an "alternative" to Diesel engines.

There is nothing inherent in gasoline engine operation that prevents the successful application of gasoline engines to heavy-duty vehicles that currently use Diesel engines. The greater durability associated with Diesel engines today is associated with engine design features (e.g., removable cylinder liners) that could be duplicated in gasoline engines specifically designed for heavy-duty service. In addition, there is a relatively small difference in the peak efficiency of gasoline and Diesel engines. Although the Diesel has certain advantages (e.g., unthrottled operation and higher efficiency at part load) that make it more desirable than gasoline engines in the current heavy-duty market, the gasoline engine may compare quite favorably to "Diesel-type" engines running on alternative fuels.

#### Heavy-Duty Methanol Engines

Options for methanol utilization in heavy-duty engines include both pre-mixed charge, spark ignition and direct injection, compression-assisted ignition operation. Heavy-duty spark ignition methanol engines resemble those used in light-duty vehicles. These engines may use either a stoichiometric mixture (generally in combination with a three-way catalyst) or a lean mixture (with an oxidation catalyst). Lean-burn engines are generally preferred for heavy-duty use, due to their greater efficiency and compatibility with existing Diesel engine designs (i.e., a lean-burn engine requires a relatively large displacement, as does a Diesel).

As a liquid, methanol can also be injected directly into the cylinder, in the same way as Diesel fuel in a Diesel engine. However, because methanol does not self-ignite readily under the conditions found in Diesel engines, some other means of ignition must be provided. Ignition techniques used in present direct-injection methanol engines include glow plugs, spark plugs, and chemical additives to promote self-ignition. In this report, we refer to these engines as "compression-assisted" ignition. Direct-injection, compression-assisted ignition methanol engines offer better efficiency than that achievable with even a lean-burn, high-compression spark ignition

methanol engine. For this reason, development of heavy-duty methanol engines has focussed primarily on this approach.

Uncontrolled Emissions - Nearly all development of heavy-duty spark ignition methanol engines has taken place in countries such as Brazil and New Zealand, where emissions are of secondary or no concern. Few emissions data on these engines are available, therefore. Limited emissions data for a lean-burn, spark ignition engine using vaporized methanol, developed by Daimler-Benz, show HC emissions around 3 g/BHP-hr and CO emissions around 2 g/BHP-hr. NOx emissions over most of the power range are in the vicinity of 2 g/BHP-hr, but they increase dramatically to around 15 g/BHP-hr at full load. This is due to mixture enrichment. The Daimler-Benz engine maintains an equivalence ratio of around 0.7 over most of the power range, but this increases to nearly 1.0 at full power.

Methanol can also be used in stoichiometric, closed-loop combustion systems such as those found in light-duty vehicles. There is little information available on the aldehyde emissions or durability of these systems under heavy-duty operating conditions, however.

Due to its poor cetane number, methanol will not self-ignite reliably in a Diesel engine; thus, some form of ignition assistance is required. Ignition approaches that have been demonstrated include spark plugs, glow plugs, and the use of ignition-improving additives mixed with the methanol. All of these approaches can produce thermal efficiencies as high as or higher than those of a conventional Diesel with lower NOx emissions and virtually no particulate matter. Emissions of unburned fuel, CO, and formaldehyde have been higher than those of Diesel engines in most cases, however, at least in the absence of a catalytic converter.

The heavy-duty methanol engines that have attracted the most attention in the U.S. are the methanol 6V-92 TA transit bus engine developed by Detroit Diesel Corporation and the methanol D2566 FMUH bus engine developed by MAN. More than 50 examples of the DDC engine and a similar number of MAN engines are now deployed in demonstrations throughout the U.S. Detroit Diesel representatives have stated publicly that the firm plans to offer only methanol engines for transit buses subject to the strict bus emissions standards effective in 1991.

The two-stroke Detroit Diesel bus engine relies on control of the scavenging airflow to maintain high enough temperatures for methanol combustion. This is supplemented by glow plug ignition at light load. The resulting control system is rather complex. This was apparently responsible for the very high unburned fuel and CO emissions exhibited by the early DDC engines. Continuing development of this engine has produced significant improvements in emissions, but unburned fuel (UBF) and CO emissions are still high compared to those of a Diesel. The MAN engine uses a more conventional spark ignition system and catalytic converter, and has demonstrated consistently good emissions performance in a number of tests, however, NOx emissions are significantly higher than achieved with the DDC methanol engines.

A number of other heavy-duty engines are undergoing more limited demonstrations. These include a glow-plug ignited methanol version of the Caterpillar 3406 truck engine, and another glow-plug ignited version of a Deutz Diesel mining engine. The use of ignition-improving additives has been tested in Cummins L10 and Daimler-Benz engines, among others.

Table 8 presents the results of a number of emissions tests on different heavy-duty methanol engines without catalytic converters, taken from a variety of sources. As this table shows, emissions of unburned fuel, aldehydes, and carbon monoxide from many of these engines are quite high, compared to those of a typical Diesel.

Table 8

Emissions from Different Heavy-Duty Methanol Engines  
Without Catalytic Converters

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>					<u>Form.</u>	<u>Cycle</u>
	<u>UBF*</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>			
<u>Detroit Diesel</u>							
Early engine <sup>25</sup>	9.7	8.6	2.1	NR	0.48		Hot Transient
SCRTD Engines <sup>26</sup>	1.0	9.0	2.0	0.06	0.10		Transient
<u>Spark-Ignited</u>							
MAN D2566 <sup>27</sup>	5.89	8.24	6.98	NR	NR		13-Mode
1-Cyl Test Engine <sup>28</sup>	6.2	8.5	6.5	NR	NR		Sim. Trans.
<u>Glow-Plug</u>							
1-Cyl Test Engine <sup>28</sup>	1.1	5.0	4.0	NR	NR		Sim. Trans.
Cat 3406 <sup>29</sup>	4.45	12.35	3.05	0.15	0.47		Transient
Deutz F8L413F <sup>30</sup>	1.1	NR	3.9	0.12	0.1		Transient
<u>Fuel Additives</u>							
1-Cyl Test Engine <sup>28</sup>	1.3	4.8	8.5	NR	NR		Sim. Trans.
Cummins L10 <sup>31</sup>	1.0	NR	5.0	low	NR		Transient
<u>Typical Diesel</u>							
1985	0.7	2	8	0.5	0.05†		Transient
1991	0.3	2	5.5	0.2	0.03+		Transient

\*Unburned fuel, measured/expressed as OMHCE.

†Total aldehydes.

Demonstrated Performance with Control Devices - The high levels of unburned methanol, CO, and aldehydes emitted by many heavy-duty methanol engines will necessitate the use of catalytic converters for emissions control. Data on the effectiveness of catalytic converters

Table 9

Emissions From Different Heavy-Duty Methanol Engines  
With Catalytic Converters

<u>Description</u>	Emissions (g/BHP-hr)					
	<u>UBF*</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>	<u>Form.</u>	<u>Cycle</u>
<u>Detroit Diesel</u> <sup>25</sup>						
Early eng./PtPd Cat	1.9	1.4	2.3	NR	0.78	Hot Transient
Early eng./PdAg Cat	6.2	4.9	2.3	NR	0.21	Hot Transient
<u>Spark-Ignited</u>						
MAN D2566 <sup>27</sup>	0.04	0.31	6.61	0.04	.001	Transient
MAN D2566 <sup>32</sup>	0.03	0.2	6.5	0.02	NR	ADB Bus

\*Unburned fuel, measured/expressed as HC.

in this role are limited and somewhat contradictory. The spark-ignited MAN methanol engine is normally equipped with a precious-metal catalytic converter which has proven extremely effective. Comparing the data in Table 9 with the corresponding uncontrolled data in Table 8, it is apparent that the MAN catalytic converter is exhibiting an efficiency well in excess of 90% for both HC and CO, and probably for aldehydes as well. Nearly all of the emissions of these pollutants that are measured are being generated in the cold-start portion of the transient test cycle--the catalyst's efficiency under warmed-up conditions is nearly 100%. The emissions measurements shown in Table 9 were taken using a nearly new catalytic converter, however, and thus probably overstate the level of emissions control attainable over the useful life of the engine.

Experience with a catalytic converter on the Detroit Diesel bus engine has been much less favorable. This two-stroke, aftercooled engine has an extremely cool exhaust, which reduces catalyst efficiency. Even so, a conventional platinum/palladium (Pt/Pd) oxidation catalyst gave good conversion efficiency for HC and CO in the hot transient test. Unfortunately, it was found that--under some conditions--this catalyst can actually produce formaldehyde by partial oxidation of methanol, resulting in a net 70% increase in the already-high formaldehyde emissions from this early-version engine. Substitution of a formaldehyde-specific palladium/silver (Pd/Ag) catalyst gave a 50% reduction in formaldehyde, but a much lower efficiency in reducing CO and HC emissions.

Potential for Further Control - The success of the catalytic emissions control system on the MAN spark-ignited methanol engine demonstrates that extremely low emissions levels can be achieved, given sufficient catalyst loading and a high-enough exhaust temperature. Other four-stroke heavy-duty methanol engines should be able to achieve similar

levels of control. The feasibility of reaching such low levels with the DDC two-stroke engine is much more questionable, due to its lower exhaust temperature and relatively high unburned fuel emissions (at least in the older versions).

### Heavy-Duty CNG Engines

Uncontrolled Emission Characteristics - Three basic types of natural gas engines have been used in heavy-duty vehicles. These are:

1. Heavy-duty gasoline-type engines, modified for use with CNG;
2. Heavy-duty Diesel engines, modified for lean spark ignition combustion; and
3. Heavy-duty Diesel engines using fumigation (mixing natural gas with the intake air).

The emissions performance of heavy-duty gasoline-type engines generally resembles that of the light-duty CNG engines discussed above. Such engines may be either dual-fuel (CNG/gasoline) or dedicated to natural gas. In the latter case, a substantial increase in compression ratio is desirable, in order to improve the thermal efficiency and power output, and reduce exhaust temperatures. For maximum power, gasoline-type CNG engines are generally calibrated for stoichiometric rather than lean operation. This calibration also permits the use of a three-way catalyst for NO<sub>x</sub> control.

Table 10 shows the results of several transient emissions tests on a gasoline-type dedicated CNG engine with two different closed-loop and one open-loop control system, all set to maintain a stoichiometric mixture.

Table 10

Uncontrolled Emissions From  
A Heavy-Duty Gasoline-Type CNG Engine  
(Source: U.S. EPA<sup>33</sup>)

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>				
	<u>THC</u>	<u>NMHC</u>	<u>CO</u>	<u>NO<sub>x</sub></u>	<u>PM</u>
TNO Closed Loop	3.57	0.83	23.29	6.87	.01
IMPCO Closed Loop	3.73	0.85	25.25	7.12	<.01
IMPCO Open Loop	3.55	0.82	31.90	6.62	.01

The design of heavy-duty Diesel engines makes them well-suited for modification to lean combustion using natural gas. Compared to gasoline-type engines, Diesels use much lower equivalence ratios (more excess air) and higher compression ratios--precisely the characteristics needed for lean CNG operation. Many Diesel engines in New Zealand, Italy, and other countries have been modified for lean CNG operation by replacing the fuel injection system with a high-energy ignition system, and adding an air-gas mixer to the intake.

In most of the Diesel engine conversions performed to date, emissions were of secondary or no concern, so that the mixture and spark timing were optimized for best efficiency, without regard to NOx. Table 11 shows the results of emissions measurements made on several lean-burn engines which had not been optimized for emissions control.

Table 11

Uncontrolled Emissions From  
Diesel Engines Converted to Lean-Burn CNG

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>					<u>Cycle</u>
	<u>THC</u>	<u>NMHC</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>	
IVECO <sup>32</sup>	1.6	NR	1.3	17	.02	AD Bus
Cummins L10 <sup>35</sup>	2.28	NR	2.06	8.27	NR	13-Mode
Cummins V903 <sup>36</sup>	2.08	NR	2.75	15.52	NR	13-Mode

Unfortunately, none of the available emissions measurements were made using the Federal Transient Test Procedure. The IVECO engine was tested using a transient test cycle which simulates city bus operation, while the two Cummins engines were tested with the old steady-state 13-mode procedure.

Partial substitution of natural gas for Diesel fuel can be attained by simply mixing the gas with the intake air. Injection and combustion of the Diesel fuel then ignites and burns the gas as well. Since the gas supplies much of the energy for combustion, the Diesel fuel delivery for a given power level is reduced. This results in reduced smoke and particulate (PM) emissions at high load, and can increase the smoke-limited power of the engine. However, incomplete combustion (especially at light loads) usually increases CO and HC emissions considerably. While work is underway to ameliorate this problem, the high HC and CO emissions from this approach presently rule it out for emission-controlled engines.

Demonstrated Performance With Control Devices - For gasoline-type heavy-duty engines, the most feasible emissions control technique is a three-way catalytic converter. Such systems are capable of attaining

very low levels of all pollutants, and have proven themselves in light-duty operation both on gasoline and gaseous fuels. The durability of three-way catalysts under the higher thermal loads experienced in heavy-duty service is not yet established, however.

Table 12 shows transient test results for three versions of a gasoline-type CNG engine equipped with a new three-way catalytic converter (results for the same configurations without the catalyst were given in Table 10). As this table indicates, the new catalytic converter reduced total HC by 62-71%, non-methane HC by 75-82%, CO by 66-72%, and NOx by 53-81%. This level of control could probably not be maintained over the long term, however, due to the accelerated aging of rhodium catalysts at high temperature. A long-term control efficiency in the range of 40-60%, corresponding to NOx emissions of around 3-4 g/BHP-hr, appears more reasonable.

Table 12

Emissions From a Heavy-Duty Gasoline-Type CNG Engine  
Equipped With a Three-Way Catalytic Converter  
(Source: U.S. EPA<sup>33</sup>)

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>				
	<u>THC</u>	<u>NMHC</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>
TNO Closed Loop	1.01	0.17	6.64	1.16	.01
IMPCO Closed Loop	1.41	0.22	7.12	3.34	.01
IMPCO Open Loop	1.03	0.15	10.77	1.33	<.01

In the case of lean-burn CNG engines, NOx cannot be controlled effectively using a three-way catalyst. NOx control in these engines is achieved through a combination of an ultra-lean mixture (for low flame temperature) and optimized ignition timing. For a typical uncontrolled lean-burn engine with equivalence ratio around 0.8, NOx emissions are typically around 15 g/BHP-hr. Reducing the equivalence ratio to 0.66 (50% excess air) reduces NOx emissions to about 3-5 g/BHP-hr. Similar reductions are possible through retarding the ignition timing. Both modifications tend to reduce fuel efficiency somewhat, however.

Table 13 shows the results of these emission control techniques on two different lean-burn engines. Although neither engine was fully optimized, the results are nonetheless quite dramatic. In both cases, NOx emissions were reduced by around 60%, with little or no adverse impact on other emissions. Fuel consumption was increased somewhat in each case, however.

Potential for Further Control - In the case of gasoline-type CNG engines, the emission results shown in Table 12 are among the lowest

ever generated by any type of engine on the Transient Cycle. These emission levels would be more than satisfactory if they could be maintained throughout the useful life of the engine. To do so will require advances in the technology of high-temperature tolerant reduction catalysts, or else advanced catalyst-protection schemes to ensure catalyst durability. Such systems are already under development for use in heavy-duty gasoline vehicles; once developed, their application to CNG engines should pose no special problems.

Table 13

Effect of Emissions Controls on Emissions From  
Diesel Engines Converted to Lean-Burn CNG

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>					<u>Cycle</u>
	<u>THC</u>	<u>NMHC</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>	
Cummins L10						
No control <sup>35</sup>	2.28	NR	2.06	8.27	NR	13-Mode
Partly optimized <sup>35</sup>	2.80	NR	2.22	3.40	NR	13-Mode
Cummins V903 <sup>36</sup>						
MBT Timing	2.08	NR	2.75	15.52	NR	13-Mode
Retarded Timing	1.23	NR	2.58	5.89	NR	13-Mode

If desired, the HC and CO emission levels shown in Table 12 could be reduced still further through the use of a dual-bed (reduction/oxidation) catalyst, with secondary air injection between the two beds. This technology has been used on some passenger cars equipped with three-way catalysts since 1980.

For lean-burn CNG engines, a substantial base of design experience with very low emission levels exists, due to the development in the last decade of advanced low-emission natural gas engines for stationary applications. By means of optimized combustion chamber shapes and turbulence and special high-energy ignition systems, manufacturers of these engines are able to ignite mixtures with equivalence ratios as low as 0.6, resulting in NOx emissions less than 2 g/BHP-hr in stationary applications. Using stratified charge techniques, even leaner mixtures can be burned, and some manufacturers of such engines are able to guarantee NOx emissions less than 1.0 g/BHP-hr for steady-state operation. For driveability reasons, engines used in vehicular applications may require a slightly richer mixture (and thus produce higher NOx emissions), but a number of workers in the field consider emissions of 3.0 g/BHP-hr or less of NOx on the transient cycle to be readily achievable.

Given sufficient NOx control through mixture and timing optimization, HC and CO control with the lean-burn engine could be achieved easily using an oxidation catalyst. This should reduce the total HC and CO values by 50 to 70% from those shown in Table 13, with non-methane HC (typically 20% of the total) reduced by an even greater fraction. Such catalysts are less sensitive to high temperatures than the rhodium used for NOx reduction, and the lean-burn engine's exhaust is much cooler in any case. Thus, temperature and durability would present no significant challenges for lean burn engine catalysts.

### Heavy-Duty LPG Engines

Uncontrolled Emission Characteristics - Heavy-duty LPG engines closely resemble those used for compressed natural gas. The two types that have been developed are:

1. heavy-duty gasoline-type engines, modified for use with LPG; and
2. heavy-duty Diesel engines, modified for lean, spark ignition combustion.

Because of its lower octane value (compared to natural gas) and poorer lean flammability, LPG is not considered a good candidate for fumigation of Diesel engines.

The emissions performance of heavy-duty gasoline-type LPG engines is generally similar to that of the gasoline-type CNG engines discussed above. Heavy-duty transient-cycle emissions measurements on an uncontrolled gasoline-type LPG engine are unavailable, but would be expected to resemble those for CNG engines. The major difference between the two would be in the non-methane HC emissions, which would make up a much larger fraction of total HC emissions in an LPG-fueled engine.

As was also the case with CNG fuel, Diesel engines are well suited to being converted to lean spark ignition operation using LPG. If the mixture and ignition timing of the resulting engine are optimized solely for performance, very high NOx emissions may result. Table 14 shows the results of transient emissions measurements on two such

Table 14  
Uncontrolled Emissions From Diesel Engines  
Converted to Lean-Burn LPG

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>				
	<u>THC</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>	<u>Cycle</u>
IVECO <sup>32</sup>	1.2	2.1	19	.02	AD Bus
MAN Bus Engine <sup>40</sup>	0.5	1.3	19	NR	13-Mode

engines. As with the CNG engines, NOx emissions from these uncontrolled engines are very high.

Demonstrated Performance With Control Devices - Three-way catalytic converters and closed-loop mixture controls have been applied both to gasoline-type and to some converted Diesel LPG engines, especially in Europe. Table 15 shows transient test results for an 11-litre converted Diesel engine operating in this mode. A large number of such engines are currently going into service in Vienna, Austria. The emissions are closely comparable to those for gasoline-type CNG engines operating in the same manner, with the exception that the non-methane HC will doubtless form a much larger fraction of the total. As with the CNG engines, the ability of the reduction catalyst to maintain this level of NOx control long-term is questionable--NOx emissions of around 3-4 g/BHP-hr over the engine's useful life appear more realistic.

Table 15

Emissions From a Heavy-Duty LPG Engine  
Equipped with a Three-Way Catalytic Converter<sup>39</sup>

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>				<u>Cycle</u>
	<u>THC</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>	
11 liter	1.05	7.31	0.90	.05	Transient

As in the case of lean-burn CNG engines, NOx emissions from lean-burn LPG engines cannot be controlled effectively using a three-way catalyst. NOx control in these engines is therefore achieved through optimizing the air-fuel mixture and ignition timing. Control of HC and CO emissions is then obtained through the use of an oxidation catalyst.

Table 16 shows emissions results for several lean-burn, heavy-duty LPG engines without catalytic converters. The top engine, a converted DAF-DKDL Diesel, is apparently the best-optimized of the group, with extremely low emissions of all three gaseous pollutants. A group of seven such engines are presently being demonstrated in buses in Amsterdam, the Netherlands, and have shown good performance in passenger service. Emissions levels for the other two engines ("A" and "B") are quite good at full power, but the 13-mode values show the effects of inadequate optimization at other operating modes. Under normal conditions, NOx emissions are highest in full-power operation--the fact that 13-mode emissions are higher than the full-power values indicates that the part-load mixture control is inadequate.

Table 16

Emissions from Heavy-Duty Lean-Burn LPG Engines<sup>39</sup>  
Optimized for Emissions Control

<u>Description</u>	<u>Emissions (g/BHP-hr)</u>				<u>Cycle</u>
	<u>THC</u>	<u>CO</u>	<u>NOx</u>	<u>PM</u>	
DAF-DKDL 1160	0.70	3.1	2.7	NR	13-Mode
Engine "A"	1.8	2.1	1.9	NR	Full Power
	2.9	3.4	4.4	NR	13-Mode
Engine "B"	1.5	2.7	2.5	NR	Full Power
	2.2	4.1	8.1	NR	13-Mode

Potential for Further Control - As with gasoline-type CNG engines, the presently-demonstrated emissions levels for stoichiometric LPG engines with three-way catalysts would be more than satisfactory if they could be maintained throughout the vehicle's useful life. HC and CO emissions could be reduced still further, however, by the use of a dual-bed catalytic converter, with additional air injection after the reduction bed. The technology for this has been well established since 1981.

The advances in high-temperature tolerant reduction catalysts and/or catalyst protection schemes required to achieve continuing high NOx conversions are likely to come about in the next few years, as a result of development of similar systems for gasoline heavy-duty vehicles. Their application to LPG engines when they are developed should be straightforward.

The substantial base of design experience with very low emission CNG engines is also largely applicable to LPG engines. Through use of high-energy ignition and optimized combustion chamber, very satisfactory NOx emission levels can be achieved, as indicated in Table 16. With the addition of an oxidation catalyst, it should be possible to reduce the HC and CO values shown in that table by around 70 to 80%, further improving the emissions picture.

#### Summary

Two conclusions can be readily drawn from the available data on alternative fuels used in heavy-duty engines. First, methanol, CNG, and LPG all exhibit substantially lower particulate emissions than Diesel engines. Second, substantially lower emissions can be achieved

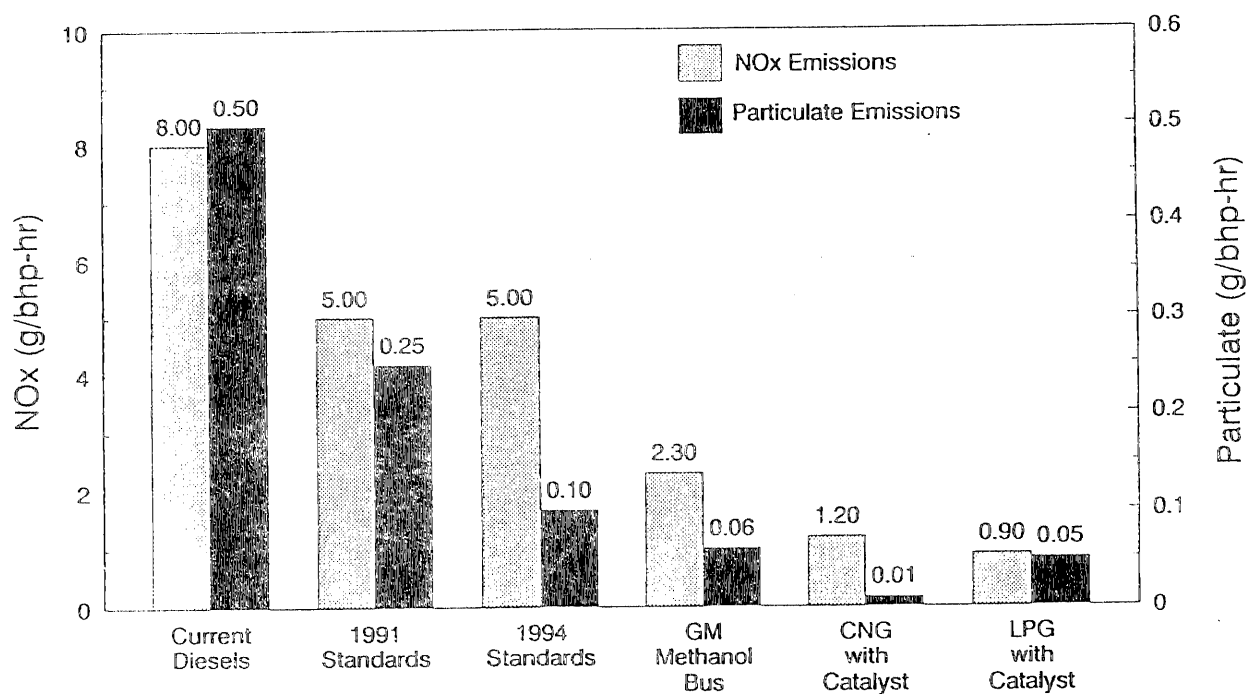
with all three of these alternative fuels through the use of catalytic emissions control.

In the case of methanol, catalytic control appears to be necessary to prevent increased formaldehyde emission levels compared to conventional Diesel engines. Formaldehyde emissions are not expected to be higher with CNG or LPG and catalytic control may not be required to achieve equivalent control of non-methane hydrocarbon. NOx emissions can be minimized with the application of 3-way catalysts.

Figure 10 compares the lowest NOx and particulate emission levels achieved with methanol, CNG, and LPG compared to conventional Diesel engines.

Figure 10

### Heavy-Duty Engine Emissions on Different Fuels (Transient Test Procedure)



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## 5. SCENARIOS FOR IMPLEMENTATION OF ALTERNATIVE CONTROL PROGRAMS

Twelve different scenarios were investigated by CMU in the work reported in a recent SAE paper entitled, "Air Quality Implications of Methanol Fuel Use". According to CMU, "The scenarios were chosen both to provide upper and lower bounds on emissions scenarios, and to approximate the possible utilization of methanol." Forecasts were made for calendar year 2000. Although not reported, the SAE paper also said that year 2010 forecasts would be developed.

The estimates of motor vehicle emissions for each scenario were provided by the Mobile Source Division of the ARB.<sup>21</sup> It was assumed that the relatively few methanol vehicles produced prior to 1992 would have the same "non-oxygenated" HC emissions as gasoline vehicles. For later model year methanol emission factors, ARB worked backwards from the assumption that methanol-fueled vehicles would emit the same amount of OMHCE as the total HC emitted by gasoline vehicles. Starting in 1995, when gasoline vehicles are projected to meet a 0.25 g/mi HC standard in customer service, methanol vehicles are assumed to emit 0.25 g/mi OMHCE. In addition, ARB assumed that one-half of the OMHCE for M85-fueled vehicles is NMHC and the other half is unburned methanol. For M100 vehicles, all of the OMHCE was assumed to be methanol and none was assumed to be NMHC. Separate estimates for formaldehyde emissions were made for each model year range.

Based on the emission factors assumed by ARB, methanol vehicles being produced today would have average emissions after 50,000 miles of customer service of 0.295 g/mi NMHC, 0.682 g/mi methanol, and 0.023 g/mi formaldehyde. Starting in 1995, M85 vehicles are assumed to achieve 50,000 mile emissions in customer service of 0.289 g/mi methanol\*, 0.125 g/mi NMHC, and 0.015 g/mi formaldehyde. "Advanced technology" M100 vehicles are assumed to emit 0.578 g/mi methanol†, zero NMHC, and 0.003 formaldehyde (the same as catalyst-equipped gasoline vehicles). Corresponding emission factors were assumed for light-duty trucks, medium-duty trucks, and heavy-duty truck emissions. Although not clearly stated in published material available to Sierra, it appears that ARB also assumed a 40% reduction in evaporative and refueling emissions for M85 and a 100% reduction for M100. In

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\* note: 0.289 methanol is equivalent to 0.125 OMHCE.

† equivalent to 0.25 OMHCE

addition, it was assumed that the use of methanol in off-road vehicles would reduce HC and NOx emissions.

In addition to the motor vehicle emission factor assumptions, ARB also directed CMU to assume that emissions associated with the refining of petroleum products would be eliminated from the basin under the methanol scenarios. Also, certain scenarios suggested by ARB included assumed NOx emission reductions for the use of methanol in stationary sources.

Not one test in ARB's data base indicates that light-duty vehicle formaldehyde emissions as low as those assumed in the emission factors provided to CMU are possible. It is also apparent that the assumption of zero non-methane/non-oxygenated hydrocarbon emissions from M100 vehicles is completely unsupported since Ford has measured significant quantities of NMHC when its FFV vehicles are operated on either M85 or M100. In addition, the demonstrated NOx emissions performance of methanol-fueled vehicles is not equivalent to the level of NOx control that has thus far been demonstrated with gasoline technology. Also, the lead time required to convert most on-road motor vehicle models to methanol would make the assumed 1990 implementation date out of the question.

The assumptions regarding the benefits of methanol use with off-road vehicles are not supported by any data indicating that methanol use would be as effective, or as cost-effective, as the application of conventional control approaches to this category. Finally, the assumptions given to CMU regarding the use of methanol-related effects on stationary sources did not appear realistic. For example, it would still appear to be economical to operate refineries to produce jet fuel, aviation gasoline, fuel oils, lube oils, and petrochemicals, as well as gasoline and Diesel fuel for use elsewhere in California, Arizona, Nevada, Oregon, Washington, and other states and countries.

Based on the above-described problems with the assumptions provided to CMU by ARB, Sierra constructed its own version of the scenarios run by CMU using the following assumptions:

1. The earliest feasible date for the widespread introduction of methanol vehicles was assumed to be 1995 instead of 1990.\*
2. Instead of zero for M100, both M100 and M85 methanol vehicle NMHC emissions were† assumed to be 50% lower than gasoline vehicle emissions.†

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\* However, even 1995 is unrealistic for total replacement of all conventional-fuel vehicles.

† i.e., 0.125 g/mi during years when gasoline vehicles are subject to a 0.25 g/mi HC standard.

3. Consistent with the available data base, methanol vehicle NOx emission factors were set at twice the levels projected for advanced technology gasoline vehicles (i.e., 0.4 g/mi for passenger cars). Heavy-duty methanol vehicles, replacing Diesel vehicles, were assumed to have NOx emissions equivalent NOx to advanced technology conventionally fueled vehicles (where gasoline engines can be used).
4. Off-road vehicles were not assumed to achieve emission reductions as a result of conversion to methanol for the foreseeable future.
5. Refineries were projected to continue in operation regardless of whether methanol fuel is introduced.
6. Other stationary sources were not assumed to achieve emission reductions as a result of conversion to methanol.
7. Evaporative and refueling emissions were assumed to be reduced by 40% with M85 and 100% with M100.

Each of the twelve scenarios is described below, including a description of any changes Sierra thought should be made to the emissions estimates based on the available test results from prototype vehicles.

CMU Scenario 1A, Baseline - According to the SAE paper published by CMU, CMU began with ARB's projected year 2000 emissions database for the South Coast Air Basin. Our personal communications with CARB staff confirmed that the data base supplied was actually a specially-constructed inventory covering the rectangular modeling area considered by CMU. It included most of the South Coast Air Basin and portions of Ventura and Santa Barbara Counties. The baseline scenario included a forecast of motor vehicle emissions based on the emission standards that had been adopted as of 1987; however, special assumptions were used regarding vehicle travel and growth rates that were prepared by the Southern California Association of Governments (SCAG). Sierra was not able to obtain a copy of the inventory provided to CMU from the ARB. The special run has apparently been purged from ARB's files.

Sierra's attempt to duplicate Scenario 1A involved the use of the standard vehicle travel data used by ARB in the "BURDEN" model. ARB's emission factor model "EMFAC7C" (the generation of the model we assume was used by CMU) was used in conjunction with the latest version of BURDEN to generate forecasts for calendar years 2000 and 2010. These motor vehicle emission forecasts were used in conjunction with our forecast of the 1985 baseline stationary source inventory for the South Coast Air Basin. Since we believe CMU used the same baseline emission factors, there were no adjustments required.

CMU Scenario 1, Projected Vehicle Standards - Under Scenario 1, mobile source emissions were reduced to account for control measures "expected to be adopted". This included passenger car and light truck standards of 0.25 g/mi HC in 1992 and 0.2 g/mi NOx in 1997. Correspondingly more stringent standards were assumed for heavier trucks. In addition, vehicles were assumed to meet the emission standards in customer service starting with the 1995 model year. This is a very optimistic assumption. Compliance with the emission standards in customer service will require substantial improvements to the I/M program. In addition, there is some question as to whether this level of performance can be achieved without regulations providing assurance that the quality of conventional fuels and motor oils will match the quality of the fuels and lubricants used during the current certification testing. Because this basic assumption of compliance in customer service was made with all other scenarios, Sierra did not believe it was necessary to modify the emission factors that ARB provided for the purposes of this study. The only change Sierra thought was needed was to incorporate the assumed adoption of more stringent standards for heavy-duty gasoline vehicles in 1994. We believe these standards were inadvertently omitted from the instructions that ARB gave to CMU. Table A-1 in Appendix A shows the differences between the emission factors used by CMU and Sierra.

CMU Scenarios 2, 8, and 9, Eliminate All Vehicle-Related Emissions - These scenarios were primarily of academic interest. All emissions from petroleum refining, gasoline marketing, and on-road and off-road motor vehicle emissions were assumed to be eliminated. Under scenario 2, both HC and NOx were eliminated. Under scenario 8, all HC was eliminated, but NOx was not changed. Under scenario 9, all NOx was eliminated, but HC was not modified.

CMU Scenario 4, 100% Advanced Conventionally-Fueled Vehicles - This scenario assumes 100% penetration of vehicles meeting the most stringent standards contained in Scenario 1 (e.g., 0.25 g/mi HC and 0.2 g/mi NOx for passenger cars and light trucks). The minor differences between the emission factors used by Sierra and CMU are listed in Table A-2 of Appendix A.

CMU Scenario 5 and 7, 100% Advanced Methanol-Fueled Vehicles - Under Scenario 5, complete penetration of advanced technology, M100-fueled vehicles is assumed (on-road and off-road). Light-duty vehicle methanol emissions are assumed to average 0.50 g/mi in customer service. Formaldehyde emissions are assumed to be equal to those from "Advanced Conventionally-Fueled Vehicles" (i.e., only 3 mg/mi). Non-methane hydrocarbon emissions are assumed to be zero. It is also assumed that methanol vehicles will be able to achieve 50% lower NOx emissions than current technology gasoline vehicles. (These basic assumptions regarding HC and NOx control were used for heavy-duty vehicles as well.) In addition, refinery shut-downs and the elimination of gasoline marketing are assumed.

Scenario 7 was just like Scenario 5 except that some stationary source NOx reductions are also assumed to occur because of a switch to methanol. NOx reductions of 20-50% from stationary source boilers and

heaters and of 50% from stationary internal combustion engines are assumed.

Sierra believes these scenarios are totally unrealistic. As discussed in Section 3, there is no basis for assuming M100 vehicles have no NMHC emissions. There is also no basis for assuming formaldehyde emissions from light-duty vehicles can be reduced to 3 mg/mi with the same level of emissions control technology that has been assumed for advanced technology vehicles using conventional fuel. Because of the problems of getting light-duty methanol vehicle NOx emissions below 0.4 g/mi, it also appears unlikely that methanol vehicles will have NOx levels as low as advanced technology gasoline vehicles. To reflect more realistic assumptions, Sierra used NMHC emissions of 0.125 g/mi and set NOx levels at twice the level for advanced technology CFVs (i.e., 0.4 g/mi for cars). The 0.125 g/mi NMHC level still reflects significant improvements over existing technology as it is half of the level reported by Ford for its Crown Victoria FFVs.

For heavy-duty vehicles, Sierra also disagrees with the assumptions given to CMU regarding reduced emissions for methanol-fueled vehicles. In the case of gasoline-powered vehicles converted to methanol, Sierra used emission factors that reflected 50% lower NMHC and higher NOx than gasoline. For converted Diesel vehicles, Sierra used emission factors that reflected 50% lower HC but equivalent NOx. (The reason for this assumption is that the NOx reductions assumed by ARB could just as easily be achieved with conventional fuels by a conversion to gasoline engines.)

Sierra did not assume any emission reductions from off-road vehicles because there is no evidence that conversion of off-road vehicles to methanol is economically and technologically feasible within the timeframe under consideration.

The assumed refinery shutdowns also appear to be unrealistic and were therefore not assumed to occur. Regardless of whether methanol use reduces the demand for refined motor vehicle fuels in the South Coast Air Basin, it would still be economic to operate the refineries to produce jet fuel, aviation gasoline, fuel oils, lube oils, and petrochemicals, as well as gasoline and Diesel fuel for use elsewhere in California, Arizona, Nevada, Oregon, Washington, and other states and countries.

Finally, Sierra believes there is no basis for assigning 20-50% NOx reductions to various stationary sources. This level of NOx control can be achieved with the use of selective catalytic reduction (SCR) systems or low-NOx burners on conventionally fueled sources.

Tables A-3 and A-5 of Appendix A compare the Sierra and CMU assumptions for these scenarios.

CMU Scenarios 6 & 12. Rapid Phase-In of Advanced Methanol Technology - All new vehicles are assumed to use "Advanced Methanol Technology" starting in 1990 under these scenarios. Under Scenario 6, 1995 and later model emission factors are the same as under Scenario 5. From

1990 through 1994, slightly higher methanol and formaldehyde emission rates are assumed. Under Scenario 12, the formaldehyde emission rate is assumed to be much higher at 55 mg/mi. However, non-methane hydrocarbons are still assumed to be zero for all model years under both scenarios. Also, refinery and gasoline marketing emissions are apparently phased-out in proportion to the phase-in of the methanol fleet. Conversion of off-road vehicles to methanol is also assumed to occur.

Sierra's version of Scenario 6 reflects Ford's findings regarding the existence of significant NMHC in the exhaust of M100 vehicles. In addition, the NOx emissions of M100 vehicles were assumed to be double the NOx emissions of gasoline vehicles. Under these assumptions, Sierra's emission factors for 1997 and later models were the same as used under Scenario 5. In addition, the beginning of the phase-in was delayed until the 1995 model year (which is still optimistic). As under Scenario 5, refinery and other stationary source emissions were left unchanged. Because Sierra did not model formaldehyde, no attempt was made to run a revised version of Scenario 12.

Table A-4 of Appendix A compares the Sierra and CMU assumptions for this scenario.

CMU Scenario 10, Slower Phase-In of Advanced Methanol Technology - 50% of all new vehicles are assumed to use "Advanced Methanol Technology" starting in 1990. Sierra did not attempt to replicate this scenario or to construct a modified version of it.

CMU Scenario 11, Rapid Phase-In of "M85" Methanol Technology - Under this scenario, all new vehicles are assumed to use 85% methanol/15% gasoline fuel starting in 1990. Average organic emissions in customer service are assumed to be 0.25 g/mi methanol and 0.125 g/mi NMHC. Formaldehyde is assumed to be 15 mg/mi. NOx emissions are assumed to be the same as conventionally-fueled vehicles. As in the case of the M100 scenarios, complete conversion of off-road vehicles to methanol and refinery shutdowns are assumed to occur.

Sierra made four basic changes to this scenario. First, the phase-in was delayed until 1995 (which is still optimistic). Second, higher NOx emission levels were assumed, as in the case of the M100 scenarios. Third, off-road vehicle emissions were left unchanged. Fourth, the refineries were assumed to continue operating.

Table A-6 of Appendix A compares the Sierra and CMU assumptions for this scenario.

###

## 6. FUTURE YEAR EMISSIONS FORECASTS FOR ALTERNATIVE CONTROL PROGRAMS

Because CMU has published its forecasts of calendar year 2000 emissions for each of the scenarios it modeled, Sierra was able to compare its own projections of the ARB assumptions with those made by CMU. Figures 11 and 12 show the results. Considering the difference in baseline inventories and mobile source travel forecasts, the agreement is quite reasonable.

After confirming that the CMU forecasts must have been done in a very similar manner, Sierra prepared year 2000 forecasts after modifying ARB's emissions assumptions to reflect our own estimates of the emission factors that should be used for the alternative assumptions. In addition, year 2010 forecasts were run for both the ARB and Sierra assumptions.

Figure 11

### Comparison of Sierra and CMU Hydrocarbon Emissions Forecasts Using ARB Assumptions

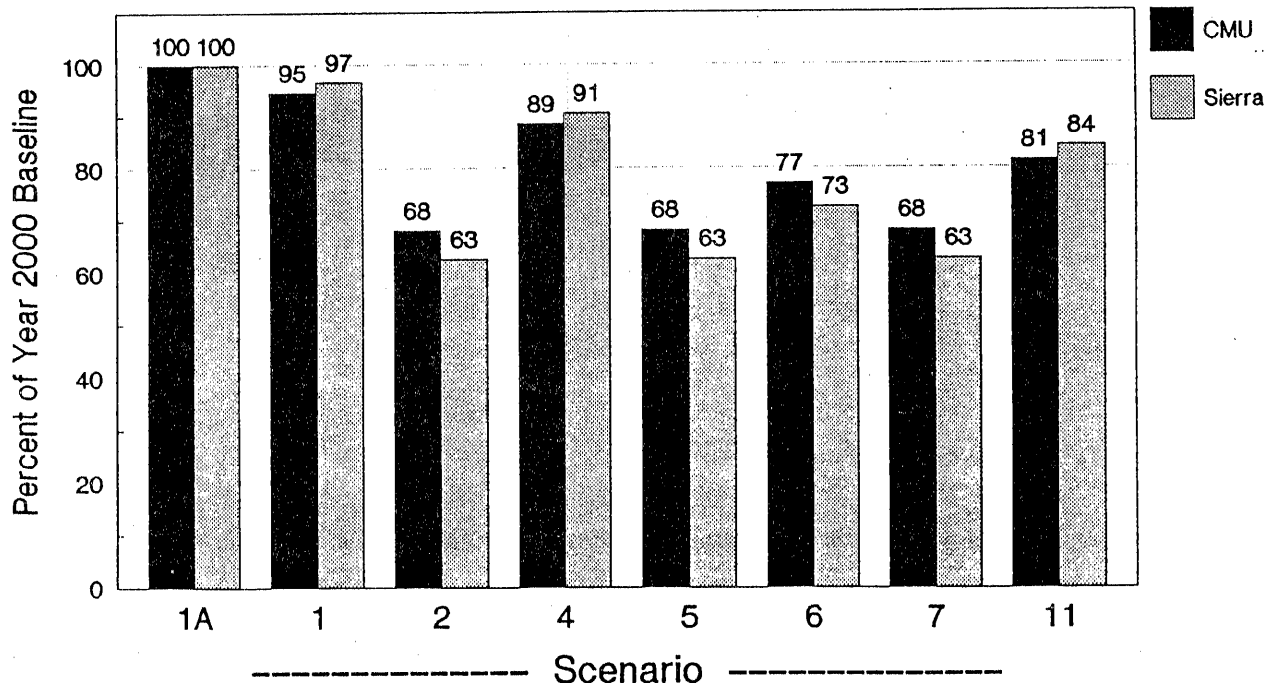
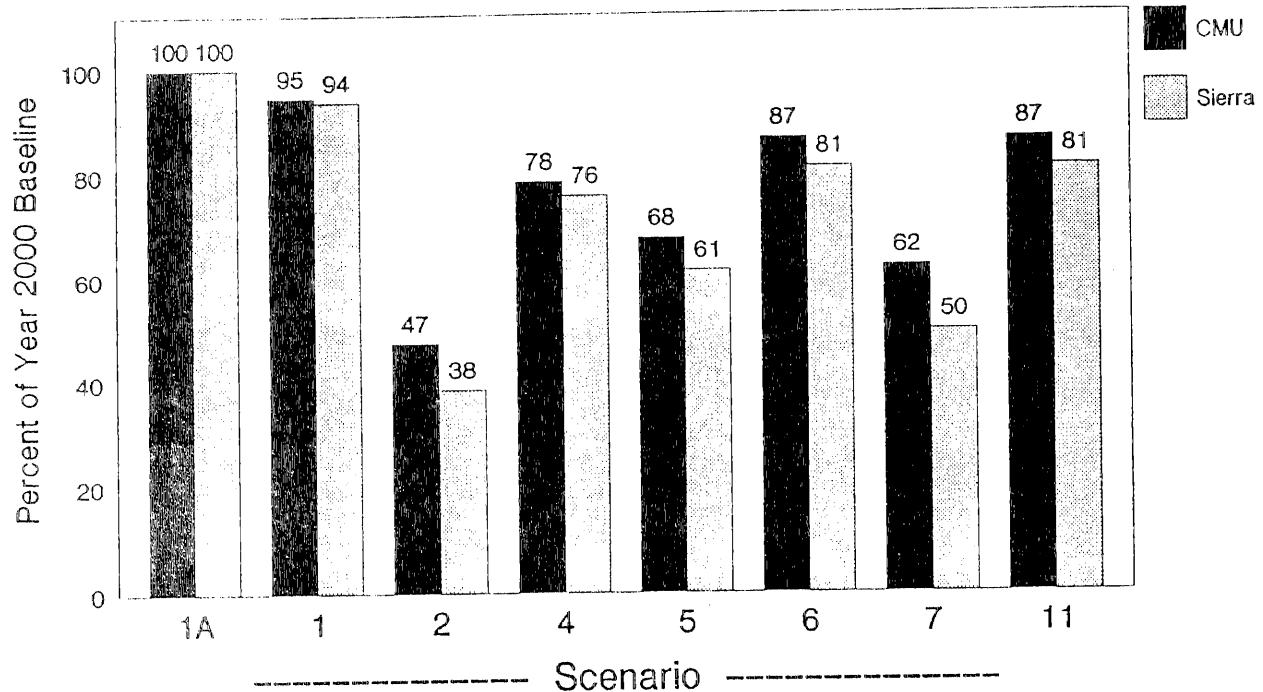


Figure 12  
**Comparison of Sierra and CMU  
 NOx Emissions Forecasts  
 Using ARB Assumptions**



The detailed comparisons of the emission forecasts using the Sierra and ARB assumptions are contained in Appendix B. As an example of how the results are tabulated in the Appendix, Tables 17 and 18 show the year 2010 emission projections for Scenario 6, involving "rapid phase-in of M100". Table 17 shows the results of using ARB's assumptions and Table 18 is based on Sierra's assumptions.

Note in Table 17, based on ARB's assumptions, there are no emissions from the category of "Stationary Sources, Fuel Combustion, Petroleum Refining". All refineries are assumed to be closed down. Likewise there are no emissions from the category "Stationary Sources, Petroleum Process, Storage & Transfer, Petroleum Refining". In contrast, Table 18 shows that Sierra's assumptions produce a total of 19.71 tons/day of hydrocarbons and 35.78 tons/day of NOx. Note also that Table 17 shows total "Other Mobile" emissions of 33.24 tons/day HC and 123.41 tons/day NOx. Table 18 shows "Other Mobile" emissions of 116.09 HC and 182.37 NOx. Significant differences are also apparent in the "On Road Vehicle" category, where ARB assumed there would be no HC emissions associated with M100 vehicles. Sierra's forecast is based on M100 vehicles emitting half the HC of gasoline vehicles and twice the NOx.

Table 17

Year 2010 Forecast of Baseline Inventory  
Scenario CMU 06 - Rapid Phase-In, M100

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
--- STATIONARY SOURCES ---		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	0.00	0.00
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	29.70	344.68
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	0.00	0.00
PETROLEUM MARKETING	0.00	0.00
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.20	0.01
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	623.25	365.40
--- MOBILE SOURCES ---		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	5.20	79.67
LIGHT AND MEDIUM DUTY TRUCKS	2.21	38.16
HEAVY DUTY GAS TRUCKS	0.71	69.91
HEAVY DUTY DIESEL TRUCKS	1.37	74.39
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	16.84	264.66
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	0.00	7.19
TRAINS	0.00	13.83
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	0.00	36.27
UTILITY EQUIPMENT	0.00	1.69
OTHER	0.00	0.00
TOTAL OTHER MOBILE	33.24	123.41
TOTAL MOBILE SOURCES	50.08	388.07
TOTAL ALL SOURCES	673.33	753.47

Table 18

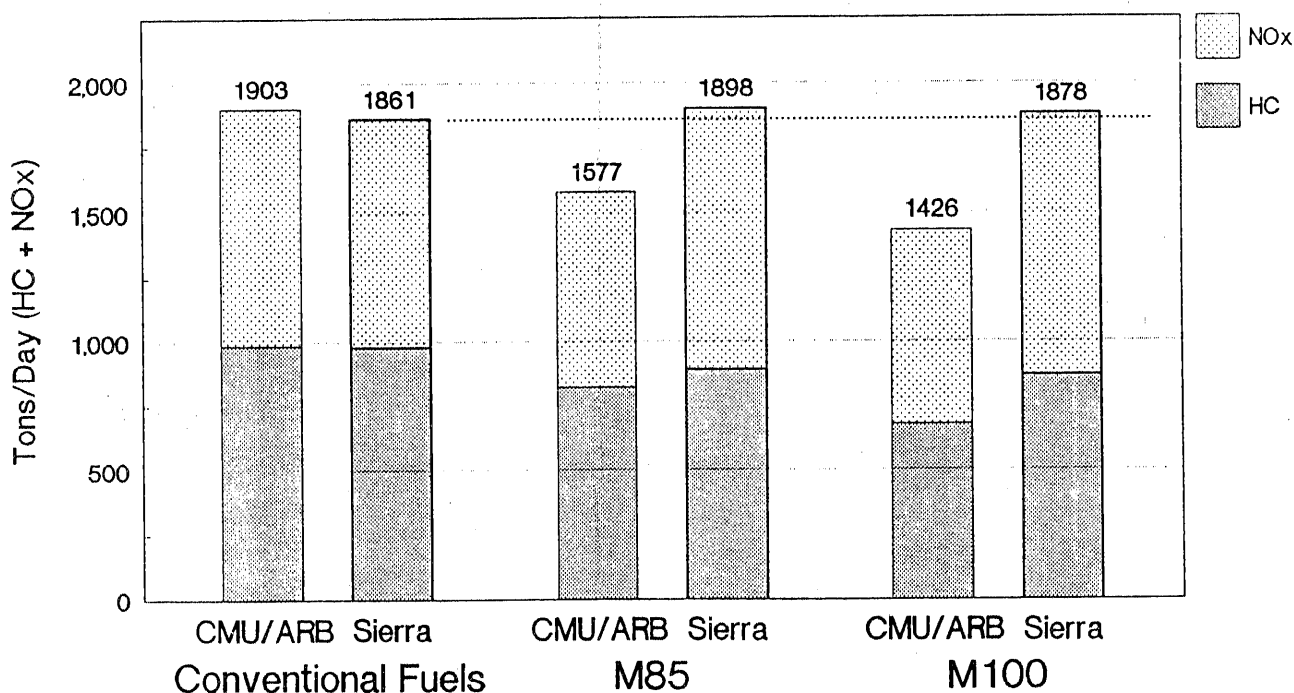
Year 2010 Forecast of Baseline Inventory  
Scenario Sierra 06 - Rapid Phase-In, M100

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
--- STATIONARY SOURCES ---		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.76
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	0.00	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	21.58	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	35.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	642.96	401.19
--- MOBILE SOURCES ---		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	52.39	134.10
LIGHT AND MEDIUM DUTY TRUCKS	20.03	77.96
HEAVY DUTY GAS TRUCKS	11.82	69.20
HEAVY DUTY DIESEL TRUCKS	18.29	142.10
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	109.87	425.92
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.09	182.37
TOTAL MOBILE SOURCES	225.96	508.29
TOTAL ALL SOURCES	868.92	1009.48

Figure 13 shows the overall comparison between the ARB and Sierra assumptions for three different cases: 1) projected standards with conventional fuels; 2) rapid phase-in of M85 (Scenario 11); and 3) rapid phase-in of M100 (Scenario 6). As the figure shows, Sierra projects that there would be no significant change in the ozone precursors (HC plus NOx) associated with a shift to either M85 or M100 fuel. Total hydrocarbon emissions are projected to be slightly lower with methanol fuel, but NOx emissions are projected to be higher. In contrast, the assumptions used by CMU lead to the conclusion that NOx plus HC emissions would be reduced by as much as 25%.

Figure 13

### Year 2010 Emission Projections CMU/ARB vs. Sierra Assumptions for Alternative Strategies



## 7. ESTIMATED AIR QUALITY EFFECTS OF ALTERNATIVE CONTROL PROGRAMS

Table 19 presents a comparison of the emission reductions (percentage) achieved under alternative scenarios developed by CMU and Sierra in the year 2000. In comparing the results it is important to remember that Sierra was unable to exactly replicate the CMU results because it did not have access to the inventory that ARB provided to them. Therefore, the baseline values presented in Table 19 are different. Nevertheless, as discussed in Section 6, Sierra was able to produce changes among the scenarios that closely tracked CMU's results.

The results provided in Table 19, therefore, illustrate the impact of changes in emission factor estimates that Sierra incorporated into the CMU scenarios. A comparison of the results for scenarios 6 and 11, the rapid methanol implementation scenarios, clearly indicates that the reductions achieved under the CMU analysis are severely degraded when more realistic assumptions and emission factor estimates are incorporated in the scenarios. By comparing the reductions achieved under the columns entitled "Sierra" with the reductions and associated ozone estimates under the columns entitled "CMU", it is apparent that neither scenario modeled by Sierra would be expected to cause a significant reduction in ozone levels, especially if more realistic formaldehyde emissions estimates are used than were employed under the CMU study.

Table 19

CMU Projections of Emissions and Ozone Changes  
vs. Sierra's Projections of Emissions Changes

Scenario	----- CMU -----			- Sierra -	
	NMHC	NOx	Ozone	NMHC	NOx
			(ppm)		
<u>Conventional Fuels:</u>					
1A. Baseline (tons/day)	1130	740	0.270	967	969
1. Projected Auto Standards	-5.3%	-5.4%	0.261	-3.7%	-8.5%
4. 100% Advanced Technology	-11.5%	-21.6%	0.246		
<u>Methanol Fuel, Including Refinery Shutdowns:</u>					
10. Slower Phase-In Advanced Technology Vehicles	-10.6%	-6.8%	0.250		
6. Rapid Phase-In Advanced Technology Vehicles	-23.0%	-13.5%	0.227	-9.0%	-3.4%
5. 100% Advanced Technology Vehicles	-31.9%	-32.4%	0.223		
7. 100% Advanced Technology Mobile and Stationary	-31.9%	-37.8%	0.219		
12. Rapid Phase-In of M100 w/55 mg/mi Formaldehyde	-22.1%	-13.5%	0.242		
11. Rapid Phase-In of M85	-18.6%	-13.5%	0.245	-8.0%	-3.4%
<u>Sensitivity Runs:</u>					
8. Eliminate Vehicle- Related HC Emissions	-31.9%	-5.4%	0.227		
9. Eliminate Vehicle- Related NOx Emissions	-5.3%	-52.7%	0.219		
2. Eliminate Vehicle- Related HC and NOx	-31.9%	-52.7%	0.206		

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## A P P E N D I X    A

### Emissions Scenarios

#### Legend:

LDA = light-duty automobiles (passenger cars)  
LDT = light-duty trucks  
MDT = medium-duty trucks  
HDG = heavy-duty gasoline vehicles (spark ignition,  
in the case of alternative fuel use)  
HDD = heavy-duty Diesel vehicles (compression  
ignition, in the case of alternative fuel use)  
N/C = no change from the emission factors  
contained in EMFAC7D

Table A-1

Emission Factor Matrix  
Scenario 1 (Projected Standards)

Model Years = Pre-1992

----- No Changes -----

Model Years = 1992-93

	----- CMU -----				----- Sierra -----			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.36	4.06	N/C	N/C				
LDT	0.37	4.40	N/C	N/C				
MDT	N/C	N/C	N/C	N/C	----- Same as CMU -----			
HDG	N/C	N/C	N/C	N/C				
HDD	N/C	N/C	N/C	N/C				

Model Years = 1994

	----- CMU -----				----- Sierra -----			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.36	4.06	N/C	N/C	0.36	4.06	N/C	N/C
LDT	0.37	4.40	N/C	N/C	0.37	4.40	N/C	N/C
MDT	0.44	6.00	0.7	N/C	0.44	6.00	0.7	N/C
HDG	N/C	N/C	N/C	N/C	1.01	13.25	2.0	N/C
HDD	N/C	N/C	N/C	N/C	N/C	N/C	N/C	N/C

Model Years = 1995-96

	----- CMU -----				----- Sierra -----			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.25	3.5	0.4	N/C	0.25	3.5	0.4	N/C
LDT	0.26	3.5	0.42	N/C	0.26	3.5	0.42	N/C
MDT	0.32	5.8	0.7	N/C	0.32	5.8	0.7	N/C
HDG	N/C	N/C	N/C	N/C	1.01	13.25	2.0	N/C
HDD	N/C	N/C	N/C	N/C	N/C	N/C	N/C	N/C

Model Years = 1997+

	----- CMU -----				----- Sierra -----			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.25	3.5	0.2	N/C	0.25	3.5	0.2	N/C
LDT	0.26	3.5	0.21	N/C	0.26	3.5	0.21	N/C
MDT	0.32	5.8	0.7	N/C	0.32	5.8	0.7	N/C
HDG	N/C	N/C	N/C	N/C	1.01	13.25	2.0	N/C
HDD	N/C	N/C	10.32	N/C	N/C	N/C	10.32	N/C

Other Changes: None

Other Changes: None

Table A-2

Emission Factor Matrix  
Scenario 4 (Full Advanced CFVs)

Model Years = All								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.25	3.5	0.2	N/C	0.25	3.5	0.2	N/C
LDT	0.27	3.5	0.25	N/C	0.27	3.5	0.25	N/C
MDT	0.34	5.8	0.78	N/C	0.34	5.8	0.78	N/C
HDG	1.01	13.25	2.0	N/C	1.01	13.25	2.0	N/C
HDD	3.0	N/C	9.24	N/C	3.0	N/C	9.24	N/C

Other Changes: None

Other Changes: None

Table A-3

Emission Factor Matrix  
Scenario 5 (Full M100 Mobile)

Model Years = All								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.0	3.5	0.2	0.0	0.125	3.5	0.4	0.0
LDT	0.0	3.5	0.25	0.0	0.13	3.5	0.5	0.0
MDT	0.0	5.8	0.78	0.0	0.16	5.8	1.56	0.0
HDG	0.0	13.25	2.0	0.0	0.50	13.25	N/C	0.0
HDD	0.0	N/C	4.62	0.0	1.50	N/C	9.24	0.0

Other Changes:

Refueling emissions = 0

Convertible off-road

sources = 0 HC, 50% NOx

Refinery emissions = 0

Other Changes:

Refueling emissions = 0

Table A-4

Emission Factor Matrix  
Scenario 6 (Rapid Phase-In of M100)

Model Years = Pre-1990

----- No Changes -----

Model Years = 1990								
----- CMU -----				----- Sierra -----				
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
LDT	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
MDT	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
HDG	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
HDD	0.0	N/C	7.20	0.0	N/C	N/C	N/C	N/C

Model Years = 1991								
----- CMU -----				----- Sierra -----				
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
LDT	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
MDT	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
HDG	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
HDD	0.0	N/C	6.56	0.0	N/C	N/C	N/C	N/C

Model Years = 1992-93								
----- CMU -----				----- Sierra -----				
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.0	4.06	N/C	0.0	0.36	4.06	N/C	N/C
LDT	0.0	4.40	N/C	0.0	0.37	4.40	N/C	N/C
MDT	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
HDG	0.0	N/C	N/C	0.0	N/C	N/C	N/C	N/C
HDD	0.0	N/C	6.56	0.0	N/C	N/C	N/C	N/C

Model Years = 1994								
----- CMU -----				----- Sierra -----				
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.0	4.06	N/C	0.0	0.36	4.06	N/C	N/C
LDT	0.0	4.40	N/C	0.0	0.37	4.40	N/C	N/C
MDT	0.0	6.00	0.7	0.0	0.44	6.00	0.7	N/C
HDG	0.0	N/C	N/C	0.0	1.01	13.25	2.0	N/C
HDD	0.0	N/C	6.50	0.0	N/C	N/C	N/C	N/C

Table A-4 (continued)

Model Years = 1995-96								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.0	3.5	0.4	0.0	0.125	3.5	0.4	-40%
LDT	0.0	3.5	0.42	0.0	0.13	3.5	0.50	-40%
MDT	0.0	5.8	0.7	0.0	0.16	5.8	1.56	-40%
HDG	0.0	N/C	N/C	0.0	0.50	13.25	N/C	-40%
HDD	0.0	N/C	6.50	0.0	1.50	N/C	N/C	N/A

Model Years = 1997+								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.0	3.5	0.2	0.0	0.125	3.5	0.4	-40%
LDT	0.0	3.5	0.21	0.0	0.13	3.5	0.50	-40%
MDT	0.0	5.8	0.7	0.0	0.16	5.8	1.56	-40%
HDG	0.0	N/C	N/C	0.0	0.50	13.25	N/C	-40%
HDD	0.0	N/C	5.16	0.0	1.50	N/C	10.32	N/A

Other Changes:

Refueling emissions = phased-out

Convertible off-road sources =

HC phased-out, NOx phased down  
by 50%

Refinery emissions = phased-out

Other Changes:

Refueling emissions =  
phased-out

Table A-5

Emission Factor Matrix  
Scenario 7 (Full M100 Mobile and Stationary)

	Model Years = All							
	----- CMU -----				----- Sierra -----			
	<u>HC</u>	<u>CO</u>	<u>NOx</u>	<u>Evap</u>	<u>HC</u>	<u>CO</u>	<u>NOx</u>	<u>Evap</u>
LDA	0.0	3.5	0.2	0.0	0.125	3.5	0.4	0.0
LDT	0.0	3.5	0.25	0.0	0.13	3.5	0.5	0.0
MDT	0.0	5.8	0.78	0.0	0.16	5.8	1.56	0.0
HDG	0.0	13.25	2.0	0.0	0.50	13.25	N/C	0.0
HDD	0.0	N/C	4.62	0.0	1.50	N/C	9.24	0.0

Other Changes:

Refueling emissions = 0

Convertible

off-road sources = 0 HC, 50% NOx

Refinery emissions = 0

Non-refinery

boilers and heaters = -20% NOx

Utility boilers = -50% NOx

Stationary I.C. engines = -50% NOx

Other Changes:

Refueling emissions = 0

Table A-6

Emission Factor Matrix  
Scenario 11 (M85 Rapid Phase-In)

Model Years - Pre-1990

----- No Changes -----

Model Year - 1990								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.295	N/C	N/C	-40%	N/C	N/C	N/C	N/C
LDT	0.305	N/C	N/C	-40%	N/C	N/C	N/C	N/C
MDT	0.34	N/C	N/C	-40%	N/C	N/C	N/C	N/C
HDG	0.79	N/C	N/C	-40%	N/C	N/C	N/C	N/C
HDD	1.5	N/C	7.20	N/A	N/C	N/C	N/C	N/C

Model Year - 1991								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.295	N/C	N/C	-40%	N/C	N/C	N/C	N/C
LDT	0.305	N/C	N/C	-40%	N/C	N/C	N/C	N/C
MDT	0.34	N/C	N/C	-40%	N/C	N/C	N/C	N/C
HDG	0.76	N/C	N/C	-40%	N/C	N/C	N/C	N/C
HDD	1.5	N/C	6.56	N/A	N/C	N/C	N/C	N/C

Model Years - 1992-93								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.18	4.06	N/C	-40%	0.36	4.06	N/C	N/C
LDT	0.185	4.40	N/C	-40%	0.37	4.40	N/C	N/C
MDT	0.34	N/C	N/C	-40%	N/C	N/C	N/C	N/C
HDG	0.76	N/C	N/C	-40%	N/C	N/C	N/C	N/C
HDD	1.5	N/C	6.56	N/A	N/C	N/C	N/C	N/C

Model Year - 1994								
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.18	4.06	N/C	-40%	0.36	4.06	N/C	N/C
LDT	0.185	4.40	N/C	-40%	0.37	4.40	N/C	N/C
MDT	0.22	6.00	0.7	-40%	0.44	6.00	0.7	N/C
HDG	0.75	N/C	N/C	-40%	1.01	13.25	2.0	N/C
HDD	1.48	N/C	6.50	N/A	N/C	N/C	N/C	N/C

Table A-6 (continued)

	Model Years = 1995-96							
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.125	3.5	0.4	-40%	0.125	3.5	0.4	-40%
LDT	0.13	3.5	0.42	-40%	0.13	3.5	0.50	-40%
MDT	0.16	5.8	0.7	-40%	0.16	5.8	1.56	-40%
HDG	0.75	N/C	N/C	-40%	0.50	13.25	N/C	-40%
HDD	1.48	N/C	6.50	N/A	1.50	N/C	N/C	N/A

	Model Years = 1997+							
	CMU				Sierra			
	HC	CO	NOx	Evap	HC	CO	NOx	Evap
LDA	0.125	3.5	0.2	-40%	0.125	3.5	0.4	-40%
LDT	0.13	3.5	0.21	-40%	0.13	3.5	0.50	-40%
MDT	0.16	5.8	0.7	-40%	0.16	5.8	1.56	-40%
HDG	0.74	N/C	N/C	-40%	0.50	13.25	N/C	-40%
HDD	1.47	N/C	5.16	N/A	1.50	N/C	10.32	N/A

Other Changes:

Refueling emissions =

phased down by 40%

Convertible off-road sources =

phased down by -50% HC, -50% NOx

Refinery emissions = phased out

Other Changes:

Refueling emissions =

phased down by 40%

A P P E N D I X   B

Emissions Summaries

Table B-1

Year 2000 Forecast of Baseline Inventory  
Scenario 1A - Current Standards, CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	5.72	28.79
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	31.28	324.32
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	34.81	0.01
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	56.24	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.40	5.99
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.55	12.48
TOTAL STATIONARY SOURCES	627.12	350.42
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	136.45	177.70
LIGHT AND MEDIUM DUTY TRUCKS	48.66	67.03
HEAVY DUTY GAS TRUCKS	20.64	61.93
HEAVY DUTY DIESEL TRUCKS	27.90	145.43
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	239.24	454.34
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	33.34	13.03
TRAINS	6.69	25.41
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	17.64	67.15
UTILITY EQUIPMENT	17.11	2.91
OTHER	0.00	0.00
TOTAL OTHER MOBILE	101.07	163.81
TOTAL MOBILE SOURCES	340.31	618.15
TOTAL ALL SOURCES	967.43	968.57

Table B-2

Year 2010 Forecast of Baseline Inventory  
Scenario 1A - Current Standards, CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.76
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	33.89	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	55.47	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	676.85	401.19
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	155.07	199.55
LIGHT AND MEDIUM DUTY TRUCKS	56.65	77.56
HEAVY DUTY GAS TRUCKS	24.00	69.90
HEAVY DUTY DIESEL TRUCKS	37.23	171.79
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	280.29	521.33
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.09	182.37
TOTAL MOBILE SOURCES	396.38	703.70
TOTAL	1073.23	1104.89

Table B-3

Year 2000 Forecast of Baseline Inventory  
Scenario CMU 01 - Projected Standards, CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	5.72	28.79
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	31.28	324.32
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	34.81	0.01
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	56.24	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.40	5.99
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.55	12.48
TOTAL STATIONARY SOURCES	627.12	350.42
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	111.45	140.55
LIGHT AND MEDIUM DUTY TRUCKS	40.88	55.27
HEAVY DUTY GAS TRUCKS	20.64	61.94
HEAVY DUTY DIESEL TRUCKS	27.90	134.06
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	206.46	394.07
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	33.34	13.03
TRAINS	6.69	25.41
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	17.64	67.15
UTILITY EQUIPMENT	17.11	2.91
OTHER	0.00	0.00
TOTAL OTHER MOBILE	101.07	163.81
TOTAL MOBILE SOURCES	307.53	557.88
TOTAL ALL SOURCES	934.65	908.30

Table B-4

Year 2000 Forecast of Baseline Inventory  
Scenario Sierra 01 - Projected Standards, CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
-----		
--- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	5.72	28.79
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	31.28	324.32
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	34.81	0.01
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	56.24	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.40	5.99
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.55	12.48
TOTAL STATIONARY SOURCES	627.12	350.42
--- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	111.45	140.55
LIGHT AND MEDIUM DUTY TRUCKS	40.88	55.27
HEAVY DUTY GAS TRUCKS	18.43	40.07
HEAVY DUTY DIESEL TRUCKS	27.90	134.06
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	204.25	372.20
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	33.34	13.03
TRAINS	6.69	25.41
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	17.64	67.15
UTILITY EQUIPMENT	17.11	2.91
OTHER	0.00	0.00
TOTAL OTHER MOBILE	101.07	163.81
TOTAL MOBILE SOURCES	305.32	536.01
TOTAL ALL SOURCES	932.44	886.43

Table B-5

Year 2010 Forecast of Baseline Inventory  
Scenario CMU 01 - Projected Standards, CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.76
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	33.89	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	55.47	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	676.85	401.19
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	91.32	79.67
LIGHT AND MEDIUM DUTY TRUCKS	34.49	38.21
HEAVY DUTY GAS TRUCKS	24.00	69.90
HEAVY DUTY DIESEL TRUCKS	37.23	142.10
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	194.37	332.41
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.09	182.37
TOTAL MOBILE SOURCES	310.46	514.78
TOTAL ALL SOURCES	987.31	915.97

Table B-6

Year 2010 Forecast of Baseline Inventory  
Scenario Sierra 01 - Projected Standards, CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.76
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	33.89	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	55.47	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	676.85	401.19
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	91.32	79.67
LIGHT AND MEDIUM DUTY TRUCKS	34.49	38.21
HEAVY DUTY GAS TRUCKS	18.87	33.85
HEAVY DUTY DIESEL TRUCKS	37.23	142.10
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	189.24	296.36
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.09	182.37
TOTAL MOBILE SOURCES	305.33	478.73
TOTAL ALL SOURCES	982.18	879.92

Table B-7

Year 2000 Forecast of Baseline Inventory  
Scenario 02 - No Vehicle Related HC or NOx

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	-	-
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	25.56	295.53
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	-	-
PETROLEUM MARKETING	-	-
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.05	0.01
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.39	5.98
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.54	12.48
TOTAL STATIONARY SOURCES	573.20	314.91
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	-	-
LIGHT AND MEDIUM DUTY TRUCKS	-	-
HEAVY DUTY GAS TRUCKS	-	-
HEAVY DUTY DIESEL TRUCKS	-	-
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	5.59	2.25
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	-	-
TRAINS	-	-
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	-	-
UTILITY EQUIPMENT	-	-
OTHER	0.00	0.00
TOTAL OTHER MOBILE	26.29	55.30
TOTAL MOBILE SOURCES	31.88	57.55
TOTAL ALL SOURCES	605.08	372.46

Table B-8

Year 2010 Forecast of Baseline Inventory  
Scenario 02 - No Vehicle Related HC or NOx

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	-	-
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	29.70	344.69
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.18	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.08	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	-	-
PETROLEUM MARKETING	-	-
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.20	0.01
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.31	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	623.25	365.42
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	-	-
LIGHT AND MEDIUM DUTY TRUCKS	-	-
HEAVY DUTY GAS TRUCKS	-	-
HEAVY DUTY DIESEL TRUCKS	-	-
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	7.34	2.53
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	-	-
TRAINS	-	-
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	-	-
UTILITY EQUIPMENT	-	-
OTHER	0.00	0.00
TOTAL OTHER MOBILE	33.24	64.43
TOTAL MOBILE SOURCES	40.58	66.96
TOTAL ALL SOURCES	663.83	432.38

Table B-9

Year 2000 Forecast of Baseline Inventory  
Scenario 04 - Full Implementation, Advanced CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	5.72	28.79
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	31.28	324.32
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	34.81	0.01
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	56.24	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.40	5.99
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.55	12.48
TOTAL STATIONARY SOURCES	627.12	350.42
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	75.23	58.46
LIGHT AND MEDIUM DUTY TRUCKS	27.73	32.17
HEAVY DUTY GAS TRUCKS	13.31	25.89
HEAVY DUTY DIESEL TRUCKS	26.23	101.44
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	148.08	220.21
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	33.34	13.03
TRAINS	6.69	25.41
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	17.64	67.15
UTILITY EQUIPMENT	17.11	2.91
OTHER	0.00	0.00
TOTAL OTHER MOBILE	101.07	163.81
TOTAL MOBILE SOURCES	249.15	384.02
TOTAL ALL SOURCES	876.27	734.44

Table B-10

Year 2010 Forecast of Baseline Inventory  
Scenario 04 - Full Implementation, Advanced CFVs

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
--- STATIONARY SOURCES ---		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.76
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	33.89	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	55.47	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	676.85	401.19
--- MOBILE SOURCES ---		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	87.86	68.68
LIGHT AND MEDIUM DUTY TRUCKS	34.17	39.86
HEAVY DUTY GAS TRUCKS	17.82	29.57
HEAVY DUTY DIESEL TRUCKS	35.45	123.87
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	182.65	264.52
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.09	182.37
TOTAL MOBILE SOURCES	298.74	446.89
TOTAL ALL SOURCES	975.59	848.08

Table B-11

Year 2000 Forecast of Baseline Inventory  
Scenario CMU 05 - Full Implementation, Advanced M100, Mobile Sources

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	-	-
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	25.56	295.53
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	-	-
PETROLEUM MARKETING	-	-
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.05	0.01
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.39	5.98
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.54	12.48
TOTAL STATIONARY SOURCES	573.20	314.91
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	-	58.46
LIGHT AND MEDIUM DUTY TRUCKS	-	32.17
HEAVY DUTY GAS TRUCKS	-	25.89
HEAVY DUTY DIESEL TRUCKS	-	50.72
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	5.59	169.49
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	-	6.52
TRAINS	-	12.71
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	-	33.58
UTILITY EQUIPMENT	-	1.46
OTHER	0.00	0.00
TOTAL OTHER MOBILE	26.29	109.57
TOTAL MOBILE SOURCES	31.88	279.06
TOTAL ALL SOURCES	605.08	593.97

Table B-12

Year 2000 Forecast of Baseline Inventory  
 Scenario Sierra 05 - Full Implementation, Advanced M100, Mobile Sources

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	5.72	28.79
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	31.28	324.32
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	-	-
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	21.43	6.71
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.39	5.98
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.54	12.48
TOTAL STATIONARY SOURCES	592.30	350.40
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	27.86	116.92
LIGHT AND MEDIUM DUTY TRUCKS	10.27	64.34
HEAVY DUTY GAS TRUCKS	4.67	61.49
HEAVY DUTY DIESEL TRUCKS	13.12	101.44
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	61.51	346.44
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	33.34	13.03
TRAINS	6.69	25.41
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	17.64	67.15
UTILITY EQUIPMENT	17.11	2.91
OTHER	0.00	0.00
TOTAL OTHER MOBILE	101.07	163.80
TOTAL MOBILE SOURCES	162.58	510.24
TOTAL ALL SOURCES	754.88	860.64

Table B-13

Year 2010 Forecast of Baseline Inventory  
Scenario CMU 05 - Full Implementation, Advanced M100, Mobile Sources

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
STATIONARY SOURCES		
FUEL COMBUSTION		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	-	-
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	29.70	344.69
WASTE BURNING		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.18	0.91
SOLVENT USE		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.08	0.08
PETROLEUM PROCESS, STORAGE & TRANSFER		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	-	-
PETROLEUM MARKETING	-	-
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.20	0.01
INDUSTRIAL PROCESSES		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.31	6.19
MISCELLANEOUS PROCESSES		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	623.25	365.42
MOBILE SOURCES		
ON ROAD VEHICLES		
LIGHT DUTY PASSENGER	-	68.68
LIGHT AND MEDIUM DUTY TRUCKS	-	39.86
HEAVY DUTY GAS TRUCKS	-	29.57
HEAVY DUTY DIESEL TRUCKS	-	61.94
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	7.34	202.58
OTHER MOBILE		
OFF ROAD VEHICLES	-	7.19
TRAINS	-	13.83
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	-	36.27
UTILITY EQUIPMENT	-	1.69
OTHER	0.00	0.00
TOTAL OTHER MOBILE	33.24	123.41
TOTAL MOBILE SOURCES	40.58	325.99
TOTAL ALL SOURCES	663.83	691.41

Table B-14

Year 2010 Forecast of Baseline Inventory  
Scenario Sierra 05 - Full Implementation, Advanced M100, Mobile Sources

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.77
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.18	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.08	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	-	-
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	21.58	6.71
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.31	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	642.96	401.20
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	34.77	137.36
LIGHT AND MEDIUM DUTY TRUCKS	13.61	79.72
HEAVY DUTY GAS TRUCKS	6.93	70.23
HEAVY DUTY DIESEL TRUCKS	17.73	123.87
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	80.38	413.71
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.10	182.37
TOTAL MOBILE SOURCES	196.48	596.08
TOTAL ALL SOURCES	839.44	997.28

Table B-15

Year 2000 Forecast of Baseline Inventory  
Scenario CMU 06 - Rapid Phase-In, M100

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
--- STATIONARY SOURCES ---		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	1.14	5.76
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	26.70	301.29
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	2.68	1.34
PETROLEUM MARKETING	6.96	0.01
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	17.69	1.36
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.40	5.99
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.55	12.48
TOTAL STATIONARY SOURCES	583.99	322.03
--- MOBILE SOURCES ---		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	42.10	140.55
LIGHT AND MEDIUM DUTY TRUCKS	15.68	55.24
HEAVY DUTY GAS TRUCKS	6.90	61.94
HEAVY DUTY DIESEL TRUCKS	5.75	83.46
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	76.02	343.43
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	6.67	7.81
TRAINS	1.34	15.25
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	3.53	40.29
UTILITY EQUIPMENT	3.42	1.75
OTHER	0.00	0.00
TOTAL OTHER MOBILE	41.25	120.40
TOTAL MOBILE SOURCES	117.27	463.83
TOTAL ALL SOURCES	701.26	785.86

Table B-16

Year 2000 Forecast of Baseline Inventory  
Scenario Sierra 06 - Rapid Phase-In, M100

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	5.72	28.79
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	31.28	324.32
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	17.41	0.01
OTHER	2.13	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	38.83	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.40	5.99
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.55	12.48
TOTAL STATIONARY SOURCES	609.71	350.42
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	94.93	154.76
LIGHT AND MEDIUM DUTY TRUCKS	35.33	70.19
HEAVY DUTY GAS TRUCKS	15.31	59.78
HEAVY DUTY DIESEL TRUCKS	19.11	134.06
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	170.26	421.03
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	33.34	13.03
TRAINS	6.69	25.41
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	17.64	67.15
UTILITY EQUIPMENT	17.11	2.91
OTHER	0.00	0.00
TOTAL OTHER MOBILE	101.07	163.81
TOTAL MOBILE SOURCES	271.33	584.84
TOTAL ALL SOURCES	881.04	935.26

Table B-17

Year 2010 Forecast of Baseline Inventory  
Scenario CMU 06 - Rapid Phase-In, M100

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
STATIONARY SOURCES		
FUEL COMBUSTION		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	0.00	0.00
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	29.70	344.68
WASTE BURNING		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
SOLVENT USE		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
PETROLEUM PROCESS, STORAGE & TRANSFER		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	0.00	0.00
PETROLEUM MARKETING	0.00	0.00
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.20	0.01
INDUSTRIAL PROCESSES		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
MISCELLANEOUS PROCESSES		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	623.25	365.40
MOBILE SOURCES		
ON ROAD VEHICLES		
LIGHT DUTY PASSENGER	5.20	79.67
LIGHT AND MEDIUM DUTY TRUCKS	2.21	38.16
HEAVY DUTY GAS TRUCKS	0.71	69.91
HEAVY DUTY DIESEL TRUCKS	1.37	74.39
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	16.84	264.66
OTHER MOBILE		
OFF ROAD VEHICLES	0.00	7.19
TRAINS	0.00	13.83
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	0.00	36.27
UTILITY EQUIPMENT	0.00	1.69
OTHER	0.00	0.00
TOTAL OTHER MOBILE	33.24	123.41
TOTAL MOBILE SOURCES	50.08	388.07
TOTAL ALL SOURCES	673.33	753.47

Table B-18

Year 2010 Forecast of Baseline Inventory  
Scenario Sierra 06 - Rapid Phase-In, M100

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.76
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	0.00	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	21.58	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	642.96	401.19
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	52.39	134.10
LIGHT AND MEDIUM DUTY TRUCKS	20.03	77.98
HEAVY DUTY GAS TRUCKS	11.82	69.20
HEAVY DUTY DIESEL TRUCKS	18.29	142.10
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	109.87	425.92
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.09	182.37
TOTAL MOBILE SOURCES	225.96	608.29
TOTAL ALL SOURCES	868.92	1009.48

Table B-19

Year 2000 Forecast of Baseline Inventory  
 Scenario CMU 07 - Full Implementation, Advanced M100, Mobile and Stationary

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
--- STATIONARY SOURCES ---		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	1.21
PETROLEUM REFINING	-	-
OTHER MANUFACTURING/INDUSTRIAL	3.28	31.60
ELECTRIC UTILITIES	15.04	91.57
OTHER SERVICES AND COMMERCE	2.78	29.24
RESIDENTIAL	1.60	22.26
OTHER	2.14	7.05
TOTAL FUEL COMBUSTION	25.56	182.93
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	-	-
PETROLEUM MARKETING	-	-
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.05	0.01
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.39	5.98
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.54	12.48
TOTAL STATIONARY SOURCES	573.20	202.31
--- MOBILE SOURCES ---		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	-	58.46
LIGHT AND MEDIUM DUTY TRUCKS	-	32.17
HEAVY DUTY GAS TRUCKS	-	25.89
HEAVY DUTY DIESEL TRUCKS	-	50.72
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	5.59	169.49
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	-	6.52
TRAINS	-	12.71
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	-	33.58
UTILITY EQUIPMENT	-	1.46
OTHER	0.00	0.00
TOTAL OTHER MOBILE	26.29	109.57
TOTAL MOBILE SOURCES	31.88	279.06
TOTAL ALL SOURCES	605.08	481.37

Table B-20

Year 2000 Forecast of Baseline Inventory  
Scenario Sierra 07

SOURCE CATEGORY  
-----

----- Tons/Day -----  
NMHC NOx  
-----

---- see Sierra Scenario 5 ----

Table B-21

Year 2010 Forecast of Baseline Inventory  
Scenario CMU 07

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
--- STATIONARY SOURCES ---		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	1.21
PETROLEUM REFINING	-	-
OTHER MANUFACTURING/INDUSTRIAL	3.49	33.37
ELECTRIC UTILITIES	18.26	111.83
OTHER SERVICES AND COMMERCE	3.04	33.65
RESIDENTIAL	1.79	22.48
OTHER	2.42	8.21
TOTAL FUEL COMBUSTION	29.70	210.75
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.18	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.08	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	-	-
PETROLEUM MARKETING	-	-
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	8.20	0.01
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.31	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	623.25	231.48
--- MOBILE SOURCES ---		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	-	68.68
LIGHT AND MEDIUM DUTY TRUCKS	-	39.86
HEAVY DUTY GAS TRUCKS	-	29.57
HEAVY DUTY DIESEL TRUCKS	-	61.94
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	7.34	202.58
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	-	7.19
TRAINS	-	13.83
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	-	36.27
UTILITY EQUIPMENT	-	1.69
OTHER	0.00	0.00
TOTAL OTHER MOBILE	33.24	123.41
TOTAL MOBILE SOURCES	40.58	325.99
TOTAL ALL SOURCES	663.83	557.47

Table B-22

Year 2010 Forecast of Baseline Inventory  
Scenario Sierra 07

SOURCE CATEGORY  
=====

----- Tons/Day -----  
NMHC NOx  
=====

---- See Sierra Scenario 5 ----

Table B-23

Year 2000 Forecast of Baseline Inventory  
Scenario CMU 11 - Rapid Phase-in of M85

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	1.14	5.76
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	26.70	301.29
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	2.68	1.34
PETROLEUM MARKETING	23.67	0.01
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	34.40	1.36
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.39	5.98
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.54	12.48
TOTAL STATIONARY SOURCES	600.69	322.03
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	77.36	140.55
LIGHT AND MEDIUM DUTY TRUCKS	28.98	55.24
HEAVY DUTY GAS TRUCKS	14.34	61.94
HEAVY DUTY DIESEL TRUCKS	15.30	83.46
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	141.57	343.44
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	20.04	7.81
TRAINS	4.01	15.25
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	10.58	40.29
UTILITY EQUIPMENT	10.27	1.75
OTHER	0.00	0.00
TOTAL OTHER MOBILE	63.69	109.57
TOTAL MOBILE SOURCES	212.76	463.84
TOTAL ALL SOURCES	813.45	785.87

Table B-24

Year 2000 Forecast of Baseline Inventory  
Scenario Sierra 11 - Rapid Phase-in of M85

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.05	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	5.72	28.79
OTHER MANUFACTURING/INDUSTRIAL	3.28	39.45
ELECTRIC UTILITIES	15.04	183.14
OTHER SERVICES AND COMMERCE	2.78	34.26
RESIDENTIAL	1.60	26.46
OTHER	2.14	9.54
TOTAL FUEL COMBUSTION	31.28	324.32
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	0.92	0.84
TOTAL WASTE BURNING	1.10	0.84
----- SOLVENT USE -----		
DRY CLEANING	21.06	0.00
DEGREASING	29.38	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	183.20	0.02
ASPHALT PAVING	3.95	0.00
PRINTING	4.27	0.05
DOMESTIC	107.33	0.00
INDUSTRIAL SOLVENT USE	21.77	0.00
OTHER	2.89	0.00
TOTAL SOLVENT USE	424.56	0.07
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	27.84	0.01
OTHER	2.15	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	49.28	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.44	1.85
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.40	4.05
METAL PROCESSES	0.71	0.08
WOOD AND PAPER	0.00	0.00
OTHER	17.99	0.00
TOTAL INDUSTRIAL PROCESSES	31.40	5.99
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	12.97	0.00
FARMING OPERATIONS	26.79	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.67	1.68
SOLID WASTE LANDFILL	5.66	0.00
OTHER	29.45	10.80
TOTAL MISCELLANEOUS PROCESSES	82.55	12.48
TOTAL STATIONARY SOURCES	620.16	350.42
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	94.93	154.76
LIGHT AND MEDIUM DUTY TRUCKS	35.33	70.19
HEAVY DUTY GAS TRUCKS	15.31	59.78
HEAVY DUTY DIESEL TRUCKS	19.11	134.06
MOTORCYCLES	5.59	2.25
TOTAL ON ROAD VEHICLES	170.26	421.03
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	33.34	13.03
TRAINS	6.69	25.41
SHIPS	1.19	34.76
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	25.10	20.50
MOBILE EQUIPMENT	17.64	67.15
UTILITY EQUIPMENT	17.11	2.91
OTHER	0.00	0.00
TOTAL OTHER MOBILE	101.07	163.81
TOTAL MOBILE SOURCES	271.33	584.84
TOTAL ALL SOURCES	891.49	935.26

Table B-25

Year 2010 Forecast of Baseline Inventory  
Scenario CMU 11 - Rapid Phase-in of M85

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
--- STATIONARY SOURCES ---		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	0.00	0.00
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	29.70	344.68
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.18	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.08	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	0.00	0.00
PETROLEUM MARKETING	20.33	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	28.53	0.02
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.31	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	643.58	365.43
--- MOBILE SOURCES ---		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	49.79	79.67
LIGHT AND MEDIUM DUTY TRUCKS	19.19	38.16
HEAVY DUTY GAS TRUCKS	13.04	69.91
HEAVY DUTY DIESEL TRUCKS	16.88	74.39
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	106.24	264.66
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	18.48	7.19
TRAINS	3.64	13.83
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	9.46	36.27
UTILITY EQUIPMENT	9.86	1.69
OTHER	0.00	0.00
TOTAL OTHER MOBILE	74.68	123.41
TOTAL MOBILE SOURCES	180.92	388.07
TOTAL ALL SOURCES	824.50	753.50

Table B-26

Year 2010 Forecast of Baseline Inventory  
Scenario Sierra 11 - Rapid Phase-in of M85

SOURCE CATEGORY	Tons/Day	
	NMHC	NOx
----- STATIONARY SOURCES -----		
----- FUEL COMBUSTION -----		
AGRICULTURAL	0.03	0.00
OIL AND GAS PRODUCTION	0.67	2.68
PETROLEUM REFINING	6.33	29.08
OTHER MANUFACTURING/INDUSTRIAL	3.49	41.72
ELECTRIC UTILITIES	18.26	223.65
OTHER SERVICES AND COMMERCE	3.04	39.14
RESIDENTIAL	1.79	26.59
OTHER	2.42	10.91
TOTAL FUEL COMBUSTION	36.03	373.76
----- WASTE BURNING -----		
AGRICULTURAL - DEBRIS	0.02	0.00
RANGE MANAGEMENT	0.16	0.00
FOREST MANAGEMENT	0.00	0.00
INCINERATION	0.00	0.00
OTHER	1.00	0.91
TOTAL WASTE BURNING	1.17	0.91
----- SOLVENT USE -----		
DRY CLEANING	23.83	0.00
DEGREASING	33.17	0.00
ARCHITECTURAL COATING	50.71	0.00
OTHER SURFACE COATING	203.54	0.02
ASPHALT PAVING	4.67	0.00
PRINTING	4.60	0.06
DOMESTIC	116.54	0.00
INDUSTRIAL SOLVENT USE	23.81	0.00
OTHER	3.21	0.00
TOTAL SOLVENT USE	464.07	0.08
----- PETROLEUM PROCESS, STORAGE & TRANSFER -----		
OIL AND GAS EXTRACTION	5.90	0.01
PETROLEUM REFINING	13.38	6.70
PETROLEUM MARKETING	20.33	0.01
OTHER	2.30	0.00
TOTAL PETROLEUM PROCESS, STORAGE & TRANSFER	41.91	6.72
----- INDUSTRIAL PROCESSES -----		
CHEMICAL	4.88	2.07
FOOD AND AGRICULTURAL	7.85	0.00
MINERAL PROCESSES	0.45	4.05
METAL PROCESSES	0.74	0.07
WOOD AND PAPER	0.00	0.00
OTHER	22.39	0.00
TOTAL INDUSTRIAL PROCESSES	36.32	6.19
----- MISCELLANEOUS PROCESSES -----		
PESTICIDE APPLICATION	13.89	0.00
FARMING OPERATIONS	20.00	0.00
CONSTRUCTION AND DEMOLITION	0.00	0.00
ENTRAINED ROAD DUST - PAVED	0.00	0.00
ENTRAINED ROAD DUST - UNPAVED	0.00	0.00
UNPLANNED FIRES	7.71	1.69
SOLID WASTE LANDFILL	6.52	0.00
OTHER	35.66	11.85
TOTAL MISCELLANEOUS PROCESSES	83.78	13.54
TOTAL STATIONARY SOURCES	663.29	401.19
----- MOBILE SOURCES -----		
----- ON ROAD VEHICLES -----		
LIGHT DUTY PASSENGER	52.39	134.10
LIGHT AND MEDIUM DUTY TRUCKS	20.03	77.98
HEAVY DUTY GAS TRUCKS	11.82	69.20
HEAVY DUTY DIESEL TRUCKS	18.29	142.10
MOTORCYCLES	7.34	2.53
TOTAL ON ROAD VEHICLES	109.87	425.92
----- OTHER MOBILE -----		
OFF ROAD VEHICLES	36.96	14.38
TRAINS	7.28	27.65
SHIPS	1.31	38.18
AIRCRAFT - GOVERNMENT	0.00	0.04
AIRCRAFT - OTHER	31.93	26.21
MOBILE EQUIPMENT	18.91	72.53
UTILITY EQUIPMENT	19.71	3.38
OTHER	0.00	0.00
TOTAL OTHER MOBILE	116.09	182.37
TOTAL MOBILE SOURCES	225.96	608.29
TOTAL ALL SOURCES	889.25	1009.48



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